CORPS OF ENGINEERS, U. S. ARMY

WAVE ACTION AND BREAKWATER LOCATION
PORT WASHINGTON HARBOR, WISCONSIN

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-334

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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Frontispiece. Aerial view of Port Washington Harbor, Wisconsin

PREFACE

Request for a model investigation of Port Washington Harbor by the Waterways Experiment Station was initiated by the District Engineer, Milwaukee District, Corps of Engineers, in a letter dated 18 May 1949. The Chief of Engineers authorized the investigation by the second indorsement thereto dated 16 June 1949. Model construction was completed in December 1949 and tests were conducted from January to November 1950.

Prior to undertaking the investigation, engineers of the Waterways Experiment Station visited the Milwaukee District Office to confer with representatives of the District Engineer concerning the prototype problem and the model study and to inspect the prototype harbor. During the course of the investigation liaison between the Milwaukee District and the Waterways Experiment Station was maintained by means of conferences and progress reports.

Personnel of the Great Lakes Division and Milwaukee District who visited the Waterways Experiment Station to attend conferences and witness model demonstrations were Colonel D. A. Morris, CE, District Engineer, Messrs. E. M. Nisen, A. R. Striegl, G. B. Wesler, and A. A. Ostermeier of the Milwaukee District, and Messrs. E. W. Nelson and W. H. Booth, Jr., of the Great Lakes Division. Others who visited the Experiment Station in connection with the study were Mr. F. A. Luber of the Wisconsin Electric Power Co., Honorable J. H. Kaiser, Mayor of the city of Port Washington, Mr. R. J. Schuknecht of the Port Washington Chamber of Commerce, Mr. O. H. Smith of Smith Bros., Inc., and Captain Harry Ellsmere of the Columbia Transportation Company. Engineers of

the Waterways Experiment Station actively connected with the model study were Messrs. E. P. Fortson, Jr., G. B. Fenwick, F. R. Brown, R. Y. Hudson, R. A. Jackson, and H. B. Wilson.

A short movie depicting the problem in Port Washington Harbor, and some of the plans proposed to solve the problem as they appeared in model tests, was made during the model study. Copies of this film are available on loan from the Research Center Library, Waterways Experiment Station.

This investigation was the second model study of wave action in Port Washington Harbor conducted by the Waterways Experiment Station. The first study was completed in 1935 and reported in Waterways Experiment Station T.M. No. 87-1, "Model Study of Proposed Improvements to the Harbor of Port Washington, Wisconsin," dated November 1935.

CONTENTS

SUMMARY

A hydraulic model investigation of the harbor at Port Washington, Wisconsin, was performed to determine whether the proposed general plan of improvement was adequate to protect the harbor from wave action and, if it were not, to devise a plan providing sufficient protection at minimum cost. A 1:100-scale concrete model geometrically similar to its prototype was used in the investigation.

It was concluded from the results of the model study that: (1) improvement plans involving installation of wave absorbers in the slips and placing of rubble along the lakeside of the north and south caisson breakwaters, in combination with the existing breakwater system, would not protect the harbor from storm-wave action; (2) either of the two small-boat basins tested would be satisfactory with respect to wave action; (3) none of the breakwater systems tested would adequately protect the outer perimeter of the expanded harbor facilities contemplated by the Wisconsin Electric Power Company; (4) the originally proposed breakwater plan would not protect the harbor from wave action; (5) a breakwater plan developed during the model study, and somewhat similar to the originally proposed plan, would be adequate to protect the harbor from storm-wave action; and (6) a rubble mound should be added on the lakeside of the existing north caisson breakwater to reduce overtopping of the structure by waves from the east to northeast directions.

WAVE ACTION AND BREAKWATER LOCATION

PORT WASHINGTON HARBOR, WISCONSIN

Model Investigation

PART I: INTRODUCTION

1. Port Washington Harbor, Wisconsin, is located on the west shore of Lake Michigan about 25 miles north of Milwaukee, Wisconsin (see location map, plate 1). The harbor is afforded some protection from storm waves by a system of converging rubble and caisson-type breakwaters forming a navigation opening 350 ft wide. The harbor area inclosed by the 3500-ft-long breakwater system comprises approximately 60 acres. About half of this area lies within navigation-depth maintenance limits. The outer harbor is maintained at a project depth of -21 ft lwd and the inner harbor, or slip area, is maintained at a project depth of -18 ft lwd (low water datum for Lake Michigan is 578.5 ft above mean tide at New York City). Plate 1 shows the existing breakwater system and shoreline structures of the harbor.

2. The harbor is exposed to surface waves generated by storms from all directions between northeast and south-southeast. These limiting directions are determined by the shape of Lake Michigan and by the location of Port Washington Harbor relative to the lake shores (plate 1). Waves caused by storms from these directions have occasioned considerable damage to harbor facilities, delays and loss of cargo during loading and unloading operations, and difficulties to ships navigating the harbor entrance. A study of critical storm conditions revealed that easterly

storms seldom generate waves as large as storms from more northerly and southerly directions because the fetch in the easterly direction is relatively short. However, waves generated by easterly storms pass through the navigation opening with little reduction in height and travel along the vertical-walled wharf of the Wisconsin Electric Power Co. into the slip areas of the inner harbor. The shallow-water area in the northern part of the outer harbor is an excellent spending beach and reduces to some extent the disturbance in the harbor resulting from southeast to south-southeast storms. Storms from the northeast usually generate larger waves than do storms from the other directions because of the longer fetch (about 195 nautical miles) in this direction. The alignment of the navigation opening is such that very little wave energy enters the harbor when waves are from the northeast. On the other hand, waves from this direction overtop the north caisson breakwater and generate waves inside the harbor which are hazardous to ships moored at the Wisconsin Electric Power Company pier and to ships navigating the harbor entrance.

3. Tentative plans for improving wave-action conditions in the harbor involved the placing of rubble wave absorbers at critical locations in the slips, placing rubble on the lakeside of the north and south caisson breakwaters, construction of a small-boat basin for pleasure craft, and extension of the lakeward end of the north breakwater for over-all improvement of harbor conditions.

4. The purpose of the model study was to evaluate the relative efficacy of the several tentatively proposed plans for protecting the harbor from storm waves, and to develop improved plans if necessary. Development of a system of improvement works which would provide optimum

protection at minimum cost was the ultimate goal. An additional benefit provided by a model of this type is that it permits a visual examination of the entire critical area which, experience has shown, is essential to a better understanding and integration of the complex and interdependent factors involved in the development of plans for harbor improvement.

PART II: THE MODEL

5. The linear scale selected for the model was based on consideration of such factors as the absolute depth of water and wave dimensions required in the model to prevent appreciable boundary-friction and surface-tension effects, available shelter space, available wave-generating and measuring devices, cost of construction, and ease of model operation. A geometrically undistorted model (equal horizontal and vertical linear scales) was necessary because of the effects of the d/L ratio (water-depth to wave-length) on the refraction, and thus wave patterns, of short-period waves. After selection of the linear scale the model was designed in accordance with the Froude[1] model laws. The following model-prototype relationships were derived based on Froude's laws, a length scale (L_r) of 1:100, and a specific-weight scale (γ_r) of 1:1:

Characteristic	Dimension[2]	Model-prototype Scale
Area	L^2	$A_r = L_r^2 = 1:10,000$
Volume	L^3	$\bar{V}_r = L_r^3 = 1:1,000,000$
Time	T	$T_r = L_r^{1/2} = 1:10$
Velocity	L/T	$V_r = L_r^{1/2} = 1:10$
Unit pressure	F/L^2	$P_r = L_r\gamma_r = 1:100$
Force	F	$F_r = L_r^3\gamma_r = 1:1,000,000$
Weight	F	$W_r = L_r^3\gamma_r = 1:1,000,000$
Energy	FL	$E_r = L_r^4\gamma_r = 1:100,000,000$

1 ASCE Manual of Engineering Practice, No. 25, "Hydraulic Models," pp 9 and 43.

2 In terms of force, length and time.

6. The model was a concrete structure 8700 sq ft in area and reproduced, to scale, the existing harbor, the shore line, and shore-line structures immediately outside the breakwater system. A sufficient area of Lake Michigan north, east, and south of the harbor was molded in conformity with existing hydrography to insure accurate reproduction of test waves from directions between northeast and south-southeast. Plate 1 shows the prototype area reproduced by the model, and figure 1 (page 13) illustrates the modeled harbor area.

7. Prototype waves were reproduced to scale by a plunger-type wave machine 60 ft in length.[3] The model waves were reproduced in accordance with the linear- and time-scale ratios listed in paragraph 5. Waves were generated by the periodic displacement incident to the periodic and vertical motion of the wave-machine plunger in water. The wave machine was mounted on rollers so that it could be positioned for the generation of waves from the different directions.

8. Wave heights in the model were measured with an electrical wave-height gage,[4] or pick-up unit, used in connection with an electrically operated recording oscillograph. The wave-height gage consisted of series-connected resistors installed in a direct-current circuit. Each resistor was so calculated that the electrical current would vary directly with submergence of the gage in water.

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3 Described in detail in Waterways Experiment Station Technical Memorandum No. 2-237, "Model Study of Wave and Surge Action, Terminal Island, San Pedro, California," dated September 1947, p 24.

4 Ibid., p 25.

PART III: TEST CONDITIONS, AND METHODS OF OBTAINING AND PRESENTING DATA

Selection of Test Conditions

Still-water level

9. All model tests were conducted using a still-water level of +2.0 ft lwd, which is the average mean monthly stage of Lake Michigan.[5] The location of Port Washington Harbor relative to the extremities of Lake Michigan is such that wind-tide and seiches should have only minor effects on local water levels.

Directions and dimensions of deep-water waves

10. Directions. The directions selected for testing the efficacy of the various improvement plans, based on considerations outlined in paragraph 2, were: northeast, north 60° east, north 75° east, east, south 75° east, south 60° east, southeast, and south-southeast. However, all of these wave directions were not used in testing every plan. The critical directions used in testing individual plans were selected on the basis of the specific purposes for which the plans were designed and the amount of protection from wave action which would be afforded the harbor by each plan for the different wave directions.

11. Dimensions. The dimensions of surface waves are determined by the speed and duration of the wind and the water distance, or fetch, over which the wind blows. In the absence of sufficient and accurate wind and

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5 U. S. Lake Survey, "Mean Monthly Water Levels of the Great Lakes, 1860-1949," U. S. Lake Survey, 630 Federal Building, Detroit, Michigan.

wave records from which model test waves could be selected, wave heights used for testing were determined from Stevenson's formula.[6] The Stevenson formula for ordinary gales and fetch distances greater than 39 nautical miles is $H = 1.5F^{1/2}$, where H is wave height in feet and F is the fetch in nautical miles. Wave periods were selected from curves developed by Sverdrup and Munk,[7] and were based on a wind speed of 28 knots and a wind duration sufficient to develop the wave heights calculated by using the Stevenson formula for the various fetches. Wave heights and corresponding wave periods selected for the different storm directions are as follows:

Storm Direction	Fetch (Nautical Miles)	Wave Height (Ft)	Wave Period (Sec)
SSE	106	15.5	6.5
SE	94	14.5	6.0
S 60° E	84	13.5	6.0
S 75° E	73	13.0	5.5
East	63	12.0	5.5
N 75° E	60	11.5	5.5
N 60° E	70	12.5	5.5
NE	195	21.0	7.5

Directions and dimensions of shallow-water waves

12. As waves approach shore over a sloping beach, and reach depths less than about one-half the deep-water wave length, certain changes begin to take place in the wave height, length, and direction of approach.

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6 Thomas Stevenson, "The Design and Construction of Harbours, A Treatise on Maritime Engineering," 3rd ed., pp 26-35. Adams and Charles Black, Edinburgh, 1886.

7 Scripps Inst. of Oceanography, "Revised Wave Forecasting, Graphs and Procedure," Wave Report No. 73, Univ. of Calif., La Jolla, Calif., March 1948.

When the waves "feel bottom," the velocity of progress decreases while the period remains constant. Therefore, the change in velocity appears as a decrease in wave length. The wave height first decreases slightly as the waves approach shallow water. Several wave lengths later, depending on the slope of the beach, wave height begins to increase rapidly, and the wave length continues to decrease until the waves become unstable and break. When a wave approaches a sloping beach at an angle, the portion of wave nearest shore begins to slow down before the portion in deeper water. Thus, the wave front begins to curve toward shore. Because of these facts and since the Port Washington Harbor model was not extended into deep water owing to model construction costs, the heights, lengths, and directions of approach of the test waves at the wave machine were not the same as the corresponding heights, lengths, and directions of approach of the selected deep-water test waves. Rather, the characteristics of the deep-water waves were determined as previously described, and were charted into the positions of the wave machine by wave-refraction diagrams.[8] The resulting wave dimensions and directions were used for model testing. The shallow-water wave characteristics which were reproduced in the model at the positions of, and by, the wave-machine plunger, compared with the corresponding deep-water waves, are shown in the following tabulation (D.W. = deep water; S.W. = shallow water):

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[8] "Breakers and Surf, Principles in Forecasting." H. O. No. 234, 1944. Issued by the U. S. Navy Department Hydrographic Office.

Wave Direction D.W.	Wave Direction S.W.	Wave Height (Ft) D.W.	Wave Height (Ft) S.W.	Wave Period (Sec) D.W. and S.W.
SSE	S 32° E	15.5	12.5	6.5
SE	S 48-1/2° E	14.5	13.0	6.0
S 60° E	S 60-1/2° E	13.5	12.5	6.0
S 75° E	S 75° E	13.0	12.0	5.5
East	S 89-1/2° E	12.0	11.0	5.5
N 75° E	N 76-1/4° E	11.5	10.5	5.5
N 60° E	N 64° E	12.5	11.0	5.5
NE	N 61° E	21.0	14.5	7.5

Breakwaters

13. Overtopping of breakwaters by waves cannot be reproduced quantitatively on a 1:100-scale model, but the most economical height of breakwaters with respect to overtopping can be determined by field observations of similar breakwaters. The heights of proposed breakwaters used in the model tests were determined in this manner by engineers of the Milwaukee District.

14. The model breakwaters reproduced to scale the shape, crown elevation, and general composition of the prototype structures. Pervious sections were constructed in the model of pea gravel with a void ratio of 35-40 per cent, and impervious sections were constructed of sheet metal, thus approximating the absorption and reflection characteristics of the prototype structures.

Electric power plant cooling water

15. All model tests were conducted reproducing to scale the discharge of cooling water into the harbor from the Wisconsin Electric Power Co. plant. This plant will discharge about 621,000 gpm when operating five 80,000-kilowatt generating units, and the velocity of efflux from the 21- by 14-ft tunnel will be about 4.8 ft per sec. The corresponding values as reproduced on the model were 6.21 gpm and 0.48 ft per sec.

Discharge was measured on the model by a Van Leer weir.[9] The point of efflux was located at the northwest limit of the coal wharf adjacent to the mouth of the Sauk River.

Method of Measuring Wave Heights

16. The occurrence of beat patterns (cyclic changes in wave height) of waves measured in the model harbor area necessitated the obtaining of oscillograph records of sufficient duration to insure that a complete picture of the variations in wave height with respect to time were recorded. It was determined from the results of preliminary tests that a wave-height record of from two to three minutes duration (model time) would be sufficient. The heights of successive waves at a given location varied with respect to time; therefore, it was necessary to determine the selected height statistically. The wave height selected for each test and position in the harbor area was the average height of the one-third highest waves occurring during an interval of two to three minutes model time. Prototype waves determined in a similar manner have been designated "significant waves."[10]

Test Data

17. Test data consisted principally of wave measurements in the outer harbor and measurements of standing waves (clapotis) at loop points

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9 B. R. Van Leer, "The California-Pipe Method of Wave Measurement," Eng. News-Record, Aug. 3, 1922, Aug. 21, 1924.

10 H. U. Sverdrup and W. H. Munk, "Wind, Sea and Swell: Theory of Relations for Forecasting," Hydrographic Office, U. S. Navy Dept., H. O. Pub. No. 601, Washington, D. C., March 1947.

along the face of the coal wharf, and along the periphery of the slips. Both types of measurements were obtained for some plans, while only the heights of standing waves were obtained for others. These latter data are less comprehensive but are considered adequate to demonstrate the effects of plans for improving wave-action conditions in the slips and along the north face of the coal wharf. For most plans where only standing-wave heights were obtained, wave-action conditions in other areas of the harbor can be determined from data on similar plans for which both types of measurements were secured. The data used for preparing wave-height contours were obtained by measuring wave heights at stations spaced on 2-ft (model) intervals in a rectangular pattern. For existing conditions the most critical wave directions were east, south 75° east, and south 60° east. However, the most critical directions for many of the improvement plans were south 60° east to south-southeast.

18. Other test data comprised photographs of results of some of the more significant tests, and visual observations of the over-all effects of proposed plans.

PART IV: TESTS AND RESULTS

Identification of Plans

19. A large number of plans and schemes of improvement were tested in the model. Tables 1 and 2 provide convenient identification of the various plans. Table 1 identifies and gives the location of each item or harbor element used to compose the different plans of improvement tested. Table 2 lists the plans in alphabetical order, shows the items added to base-test conditions for each plan, and lists by number the plates which present model wave-height data for each plan. The elements of all improvement plans, except items X-A and X-2, are shown on plate 2. Item X-A is shown on plate 33 (plan N-1), and item X-2 is shown on plate 45 (plan W).

Base Test

Test conditions

20. The term "base test" is used in model investigations to denote tests conducted with existing prototype conditions installed in the model. The purpose of such tests is to obtain basic data with which the results of tests of various improvement plans can be compared. The prototype features used as base-test conditions usually include those elements existing in the harbor prior to the model study and any improvements contemplated or authorized which would be installed regardless of model-study results (improvements not related to or involved in the problems with which the model study is concerned). There were no changes of existing harbor elements authorized during the period of the Port Washington Harbor model study. Therefore, base tests were conducted in the model with

existing harbor elements installed. The harbor elements used to represent base-test conditions are shown by figure 1 and plate 3.

Test results

21. The data obtained with base-test conditions installed in the model indicate that storms from the directions between south 60° east and north 60° east cause very adverse wave-action conditions in the outer and inner harbors, as shown on plates 4, 5 and 6A. Figure 1 illustrates wave patterns in the model harbor with 5.5-sec waves 12 ft high from the east. The magnitudes of these waves are shown on plate 5A. Storm waves from southeast and northeast (plates 3B and 6B) also cause

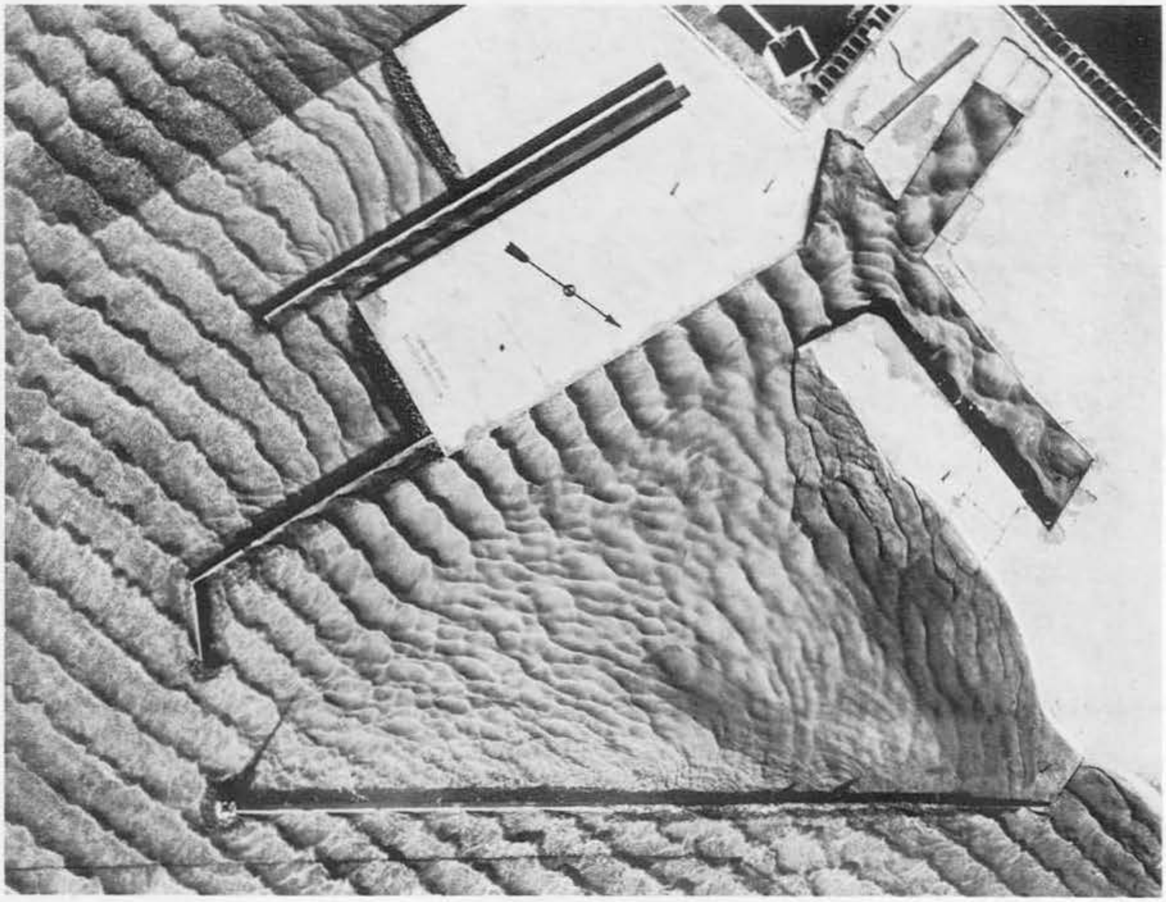


Figure 1. Wave action in harbor, with base test conditions installed, created by 5.5-sec waves 12-ft high from the east

adverse wave conditions in the problem area. Storms from south-southeast are capable of generating waves at Port Washington Harbor larger than from any other direction except that of northeast. However, model tests showed that waves from south-southeast disturb the harbor less than do storm waves from any other direction (see plate 3A).

Plans A, B, C, D, E, E-1, F

Description of plans

22. The principal feature common to each of these plans was the use of various combinations of protective works (rubble-mound wave absorbers) with the existing breakwater system to effect the desired protection within the harbor. Plans A, B, and C proposed the use of protective works only, while plans D, E, and E-1 included a small-boat basin in addition to the protective works. Plan F involved the installation of protective works, extensions to the Wisconsin Electric Power Co.'s wharves, dredging of a ship channel, and construction of a combination pier and breakwater flanking the dredged channel. The elements of these plans are shown on plate 2 and described in detail in the following subparagraphs.

- a. Plan A, in addition to base-test conditions, consisted of installing a mound of rubble on the lakeside of the existing north (item 6) and south (item 7) caisson breakwaters (section A type breakwater shown on plate 2).
- b. Plan B involved the addition to base-test conditions of item 1, a rubble wave absorber installed at the west end of the west slip, and item 4, a rubble wave absorber located at the junction of the north and west slips.
- c. Plan C represented the ultimate development of schemes using wave absorbers in critical areas of the inner harbor. In addition to items 1 and 4, this plan included item 2 (rubble wave absorber at the north end of the north slip) and item 3 (rubble wave absorber along the east face of

the pier head between the Sauk River and west slip).

d. Plan D consisted of items 1, 2, 4, and 5. Item 5 was a small-boat basin 150 ft wide and 900 ft long with an access channel dredged from the north slip, plus a filled area around the basin.

e. Plan E combined the elements of plans A and B with items 12 and 13. Item 12 consisted of a small-boat basin north of and adjacent to the existing harbor with an access channel dredged from the outer harbor. Item 13 was a 200-ft rubble-mound wave-deflector stub projecting from the harbor side of the north breakwater.

f. Plan E-1 was identical to plan E except that item 13 was omitted.

g. Plan F consisted of the protective works of plans A and C (items 1, 2, 3, 4, 6 and 7) plus item 11. The latter item involved extension of the Wisconsin Electric Power Co.'s north and south coal wharves in combination with construction of a 200-ft-wide channel dredged to a project depth of -21 ft lwd, and located immediately south of and parallel to the south wharf. Item 11 also included a combination pier and rubble-mound breakwater 1650 ft in length, flanking the dredged channel of the south wharf extended.

Test results

23. Plan A was designed to improve harbor conditions by reducing overtopping of the north and south caisson breakwaters. The plan was effective in reducing overtopping of the breakwaters for storm waves from directions between south 75° east and northeast (plates 8B, 9, and 10). The effectiveness of item 6 in reducing overtopping of the north caisson breakwater with waves from the east can be seen by comparing the wave patterns shown on figures 1 and 2 (pages 13 and 16). For storms from the southeast (plate 7B) and south 60° east (plate 8A), wave heights along the coal wharf and in the slips were increased by the installation of plan A. It is believed that this is owing to the change in wave-front patterns at the navigation opening caused by the rubble-mound

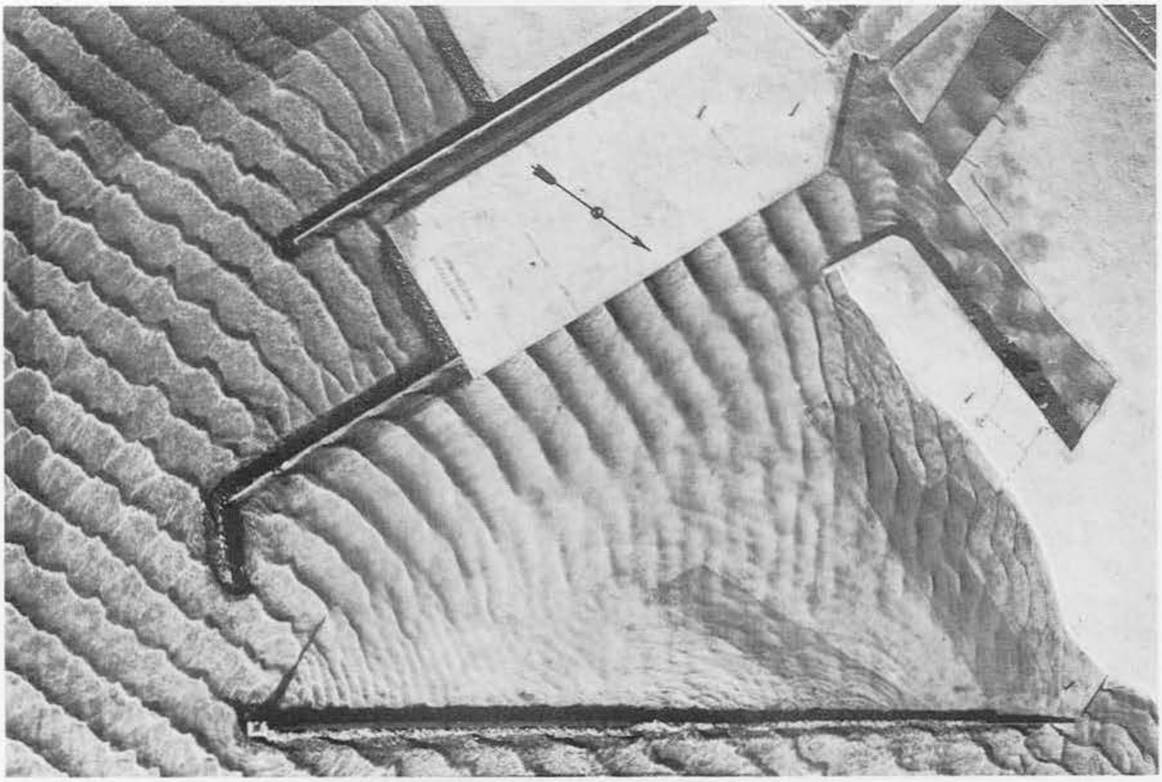


Figure 2. Plan A with 5.5-sec waves 12-ft high from the east

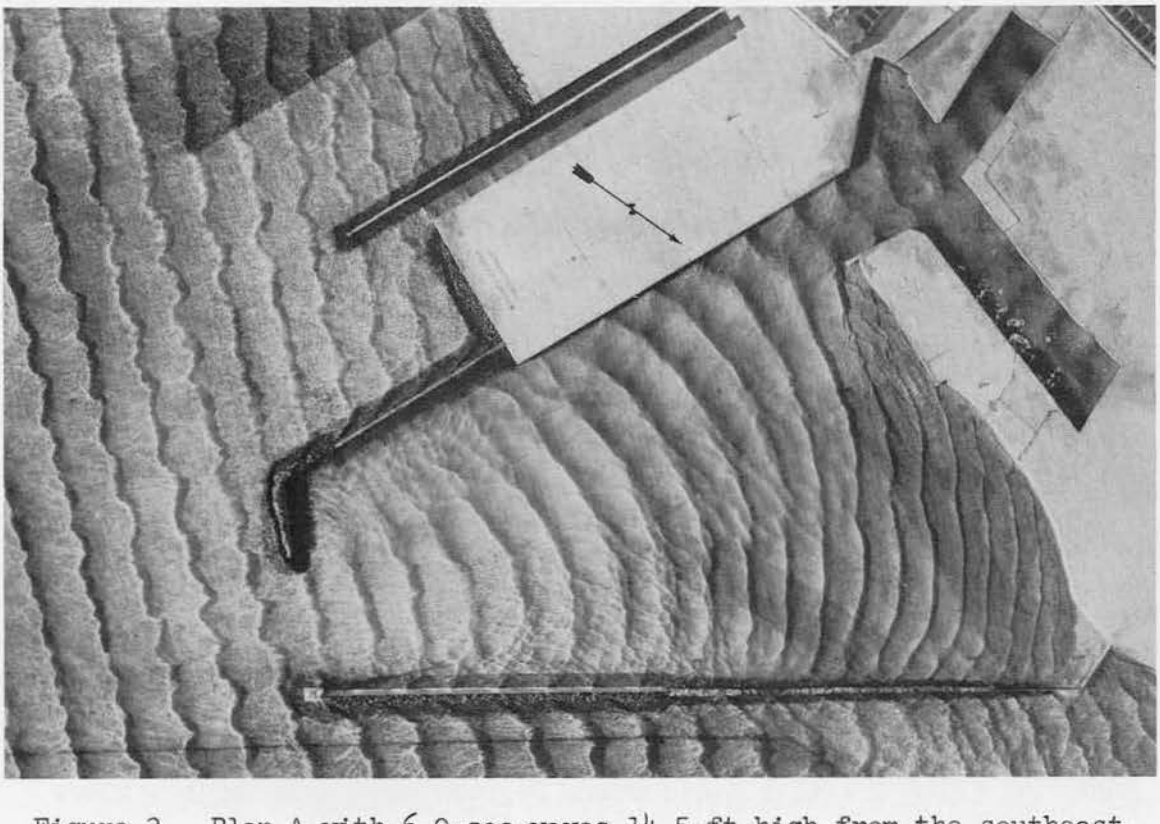


Figure 3. Plan A with 6.0-sec waves 14.5-ft high from the southeast

addition (item 7) to the south caisson breakwater (see figs. 2 and 3). Conditions in the outer harbor were slightly better with little change in inner harbor conditions for waves from the south-southeast (plate 7A).

24. The results of tests on plan B, shown on plates 11 and 12, indicated that wave-action conditions in the outer harbor were not improved by the installation of the plan-B wave absorbers, except for a slight reduction of wave heights along the coal wharf for southeast storms. Plan B improved conditions in the slips for all directions tested. On an average, and with respect to base-test conditions, wave heights in the west slip were reduced about 60 per cent, and in the north slip the reduction was in the range of 30-40 per cent.

25. With the four wave absorbers of plan C in the slips, wave

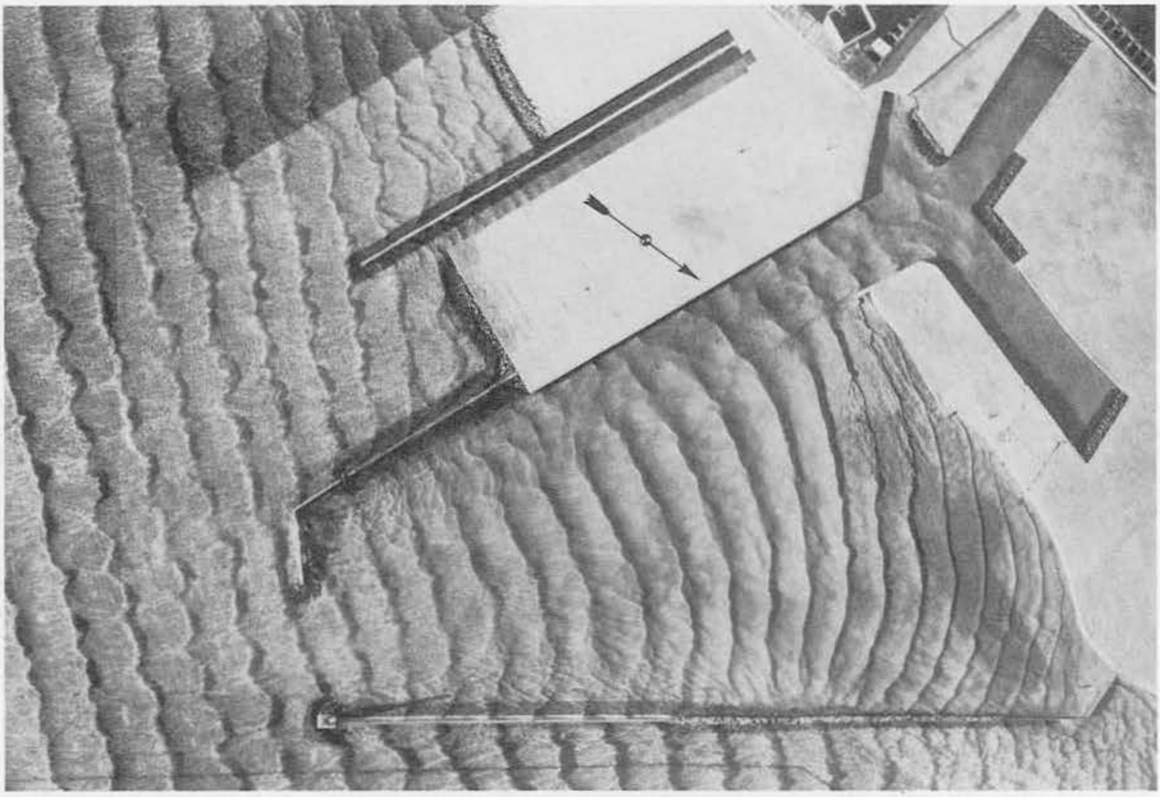


Figure 4. Plan C with 6.0-sec waves 14.5-ft high from the southeast

action along the coal wharf was reduced slightly, but over-all conditions in the outer harbor were not altered (see plates 13-14). Excellent reduction of the heights of standing waves in the slips resulted from the installation of this plan. Figure 4 depicts the tranquil conditions in the inner harbor with plan C installed. The wave absorbers were disposed so that wave-reflecting surfaces were reduced to a minimum.

26. Plan D was about as effective as plan B in reducing standing waves in the slips. The item 5 small-boat harbor was found to be satisfactory. Test results indicated that the reduction of area in the outer harbor occasioned by the fill around the small-boat harbor would have little effect on over-all wave conditions in the outer harbor. This was owing to the fact that the outer perimeter of the fill area consisted of a rubble slope which was a good wave absorber. Test results of plan D are shown on plates 15 and 16.

27. Plan E, like plan B, proved beneficial to the inner harbor area (plates 17 and 18A). In addition, the item-6 rubble wave absorber provided protection from waves from the northeast (plate 18B). Conditions in the item 12 small-boat harbor were excellent. Plan E-1 (plan E less item 13) was tested to determine the effectiveness of the item 13 stub breakwater. Comparison of figures 5 and 6 shows that the stub breakwater was not very effective in providing added protection to the small-boat harbor.

28. Wave-height data obtained with plan F installed (plates 19 and 20) indicate that installation of four wave absorbers in the inner harbor provided excellent reduction of wave heights in the slips, as was the case in plan C. However, the lakeside addition of the rubble, items

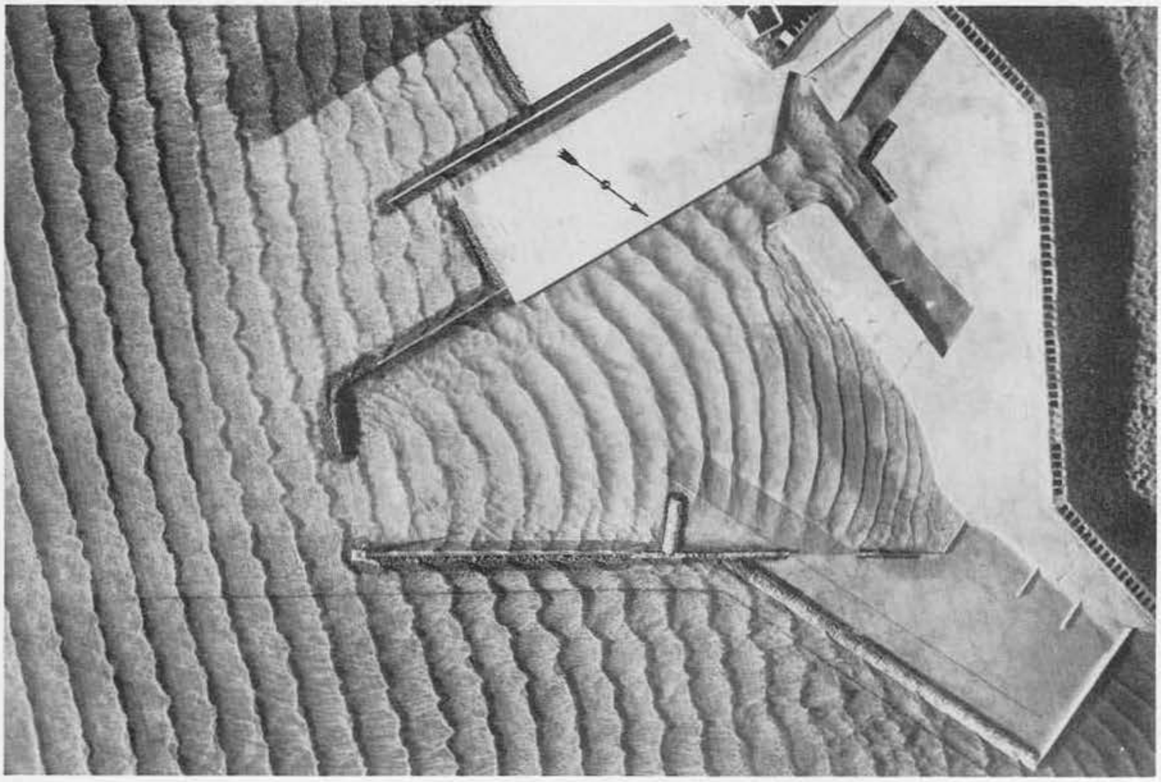


Figure 5. Plan E with 6.0-sec waves 14.5-ft high from the southeast

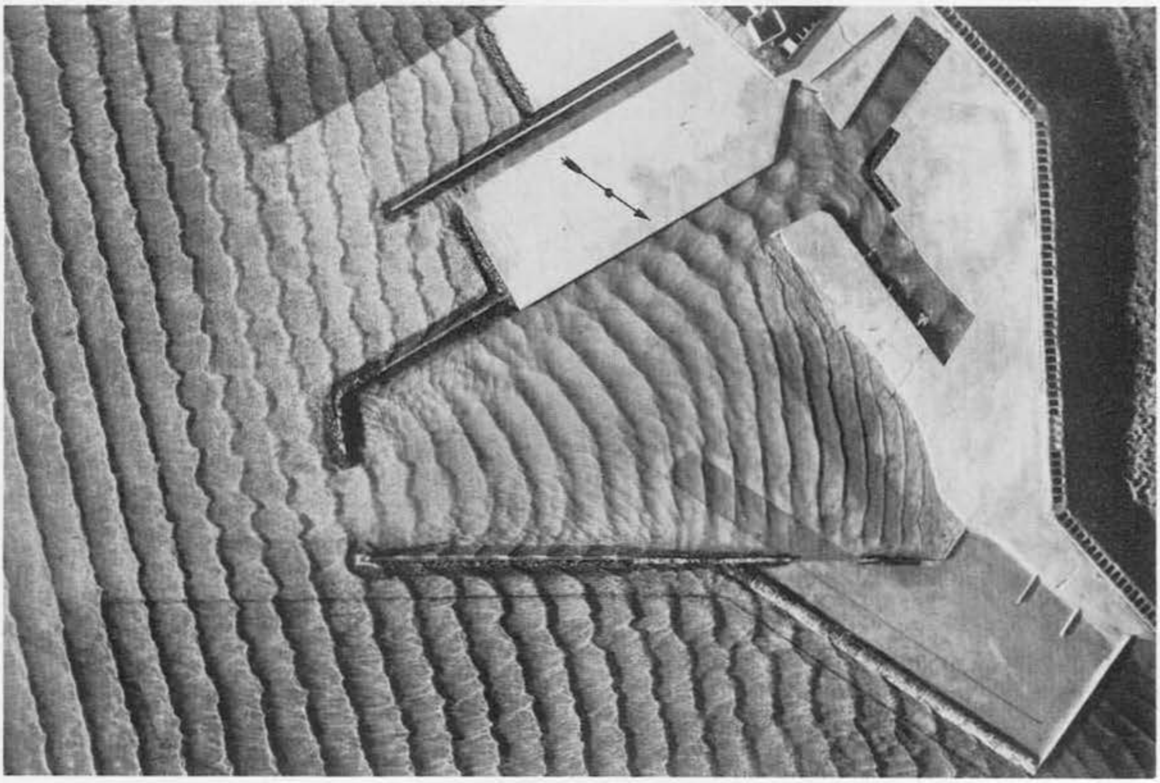


Figure 6. Plan E-1 with 6.0-sec waves 14.5-ft high from the southeast

6 and 7, had little effect on wave-action conditions in the outer harbor. Wave action along the faces of the extended coal wharves (item 11) would be unfavorable for shipping. Wave heights along the extended coal wharf on the inside of the existing harbor ranged from a maximum of 11 ft to a minimum of 3 ft. Wave heights on the south side of the south coal wharf extended were very large (5-16 ft).

Plans G, H, and I

Description of plans

29. Three items (8, 9, 10) involving modifications to the existing breakwater system, plus item 6 (rubble mound installed lakeside of north caisson breakwater), were common to plans G, H, and I. The modifications to the breakwater system consisted of a 1200-ft lakeward extension (section D type) of the north breakwater (item 8) in combination with a detached breakwater 1000 ft in length (item 9) positioned so that a 600-ft navigation opening was provided between the ends of the extended north breakwater and the detached section. In addition, the south caisson breakwater was removed to -22 ft lwd (item 10). These items together with the distinguishing elements of each plan as described below are shown on plate 2.

- a. Plan G, in addition to items 6, 8, 9, and 10, included rubble wave absorbers in the inner harbor (items 1 and 4).
- b. Plan H omitted the wave absorbers in the inner harbor and included item 12 (small-boat harbor north of and adjacent to the existing harbor) and item 13 (rubble wave deflector) in addition to items 6, 8, 9, and 10.
- c. Plan I was similar to plan H except that items 12 and 13 were omitted and item 11 (wharf extensions, dredged channel, and combination pier and rubble breakwater) was added.

Test results

30. Plate 21 shows results of tests of plan G on waves from south-southeast and southeast. These data indicate that plan G provided fair reduction of wave action along the coal wharf and in the slips; however, over-all conditions in the harbor were not improved appreciably. It was also observed during tests that plan G provided the harbor excellent protection from waves from directions between northeast and south 60° east.

31. Plan H provided the harbor good protection against waves from the east and northeast, but practically no protection from waves from the south-southeast (see plates 22 and 23). Test data indicate that the item 12 small-boat harbor would be satisfactory for all conditions tested.

32. Tests of plan I indicated unsatisfactory wave-action conditions in the harbor for storm directions between south-southeast (see fig. 7)

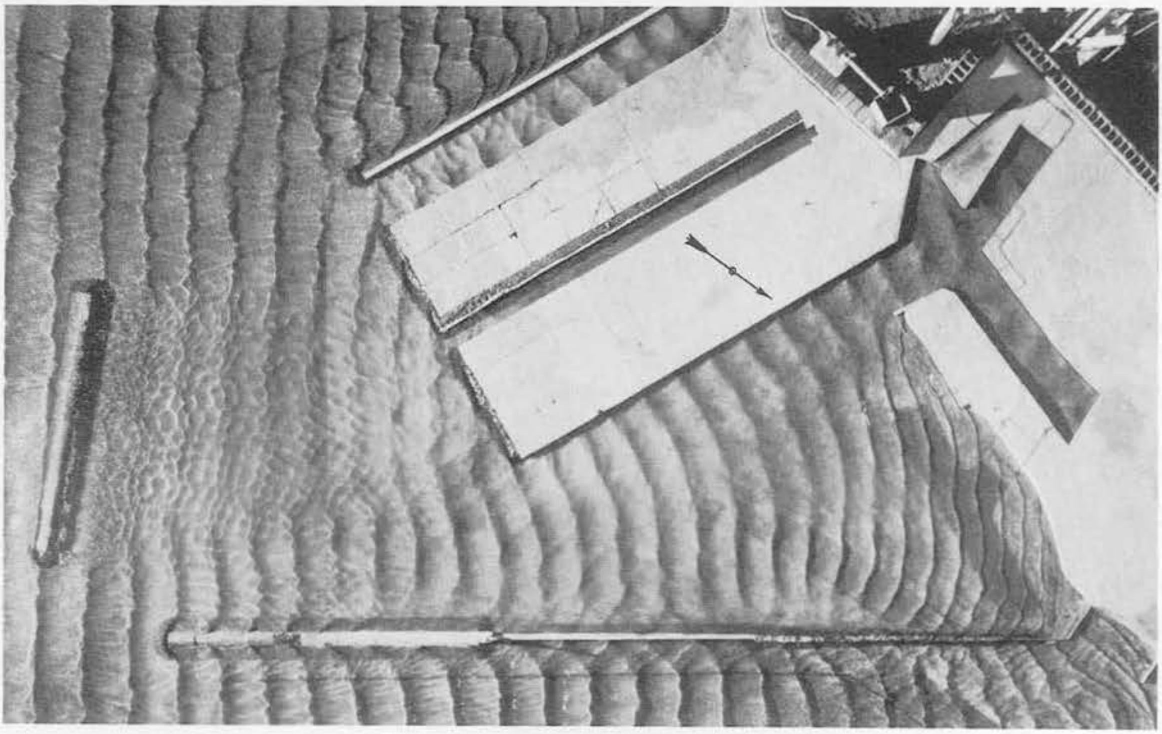


Figure 7. Plan I with 6.5-sec waves 15.5-ft high from south-southeast

and south 60° east as shown by the data on plates 24 and 25. Plan I provided the harbor good protection against waves from the east and northeast (plate 26). Item 11 was designed to provide additional berthing space for shipping. However, test results indicated that wave-action conditions would cause these facilities to be practically useless for this purpose except in calm weather.

Plans J, K, L, M, N, N-1, O

Description of plans

33. The primary element of this series of plans consisted of the item X lakeward extension of the north breakwater. This extension was an alternate to the originally proposed plan which involved items 8 and 9. The item X breakwater was about 2050 ft long, or about 150 ft shorter than the breakwaters of items 8 and 9 combined. Plate 2 shows the difference in alignment between the originally proposed breakwater system (items 8 and 9) and its alternate (item X). Another common feature of this series of plans was the removal of the south caisson breakwater (item 10). This feature was designed to facilitate ingress and egress of the harbor. Plan J consisted solely of items 10 and X, while plans K, L, and M included plan J with the addition of various protective works. Plans N, N-1, and O omitted the protective works and were concerned with variations of items 11 and X in addition to item 10. The elements of the plans are shown on plate 2, except those of plan N-1, and are described below.

a. Plan J, as stated above, consisted of items 10 and X.

b. Plan K was identical to plan J except for the addition of the wave absorber at the junction of the north and west slips (item 4).

c. Plan L included all of the plan K elements plus the wave absorber in the west end of the west slip (item 1).

d. Plan M was identical to plan J with item 6 (rubble on lakeside of north caisson breakwater) added.

e. In plan N, items 10 and X were combined with the wharf extension and related elements of item 11.

f. Plan N-1 was the same as plan N except that item X-A was substituted for item X. Item X-A consisted of item X plus a 230-ft wave deflector installed at the northeast corner of the extended north coal wharf, as shown on plate 33.

g. Plan O was identical to plan N except that the length of the extension of the coal wharves and the related elements of item 11 were reduced 150 ft (item 11-A).

Test results

34. Plan J provided the harbor moderate protection against south-southeast storm waves (plate 27A) and excellent protection against waves from southeast and directions south of east (figs. 8 and 9 and plates 27B

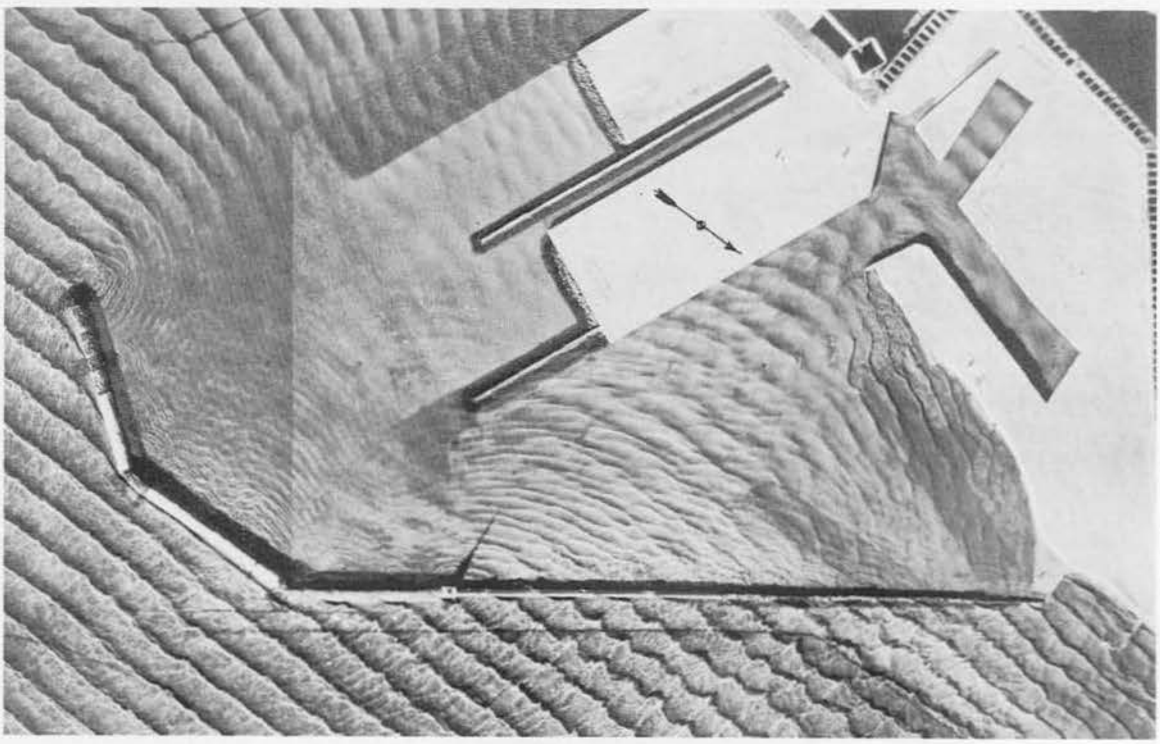


Figure 8. Plan J with 5.5-sec waves 12-ft high from the east

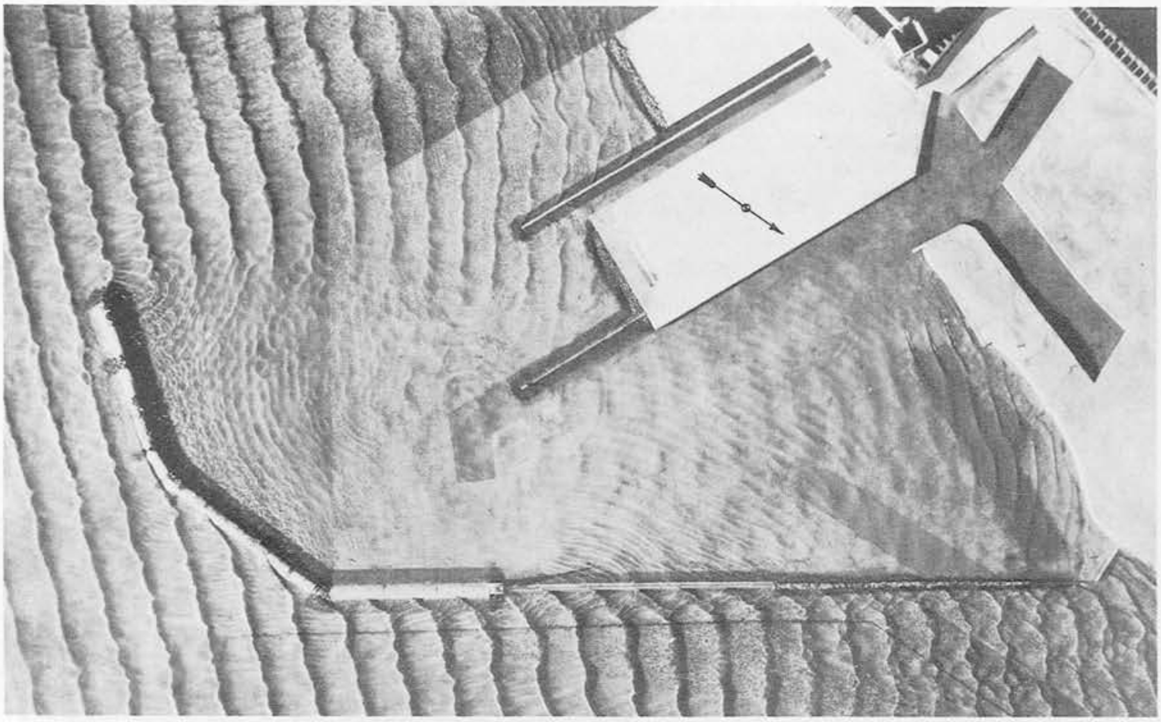


Figure 9. Plan J with 6.0-sec waves 14.5-ft high from the southeast

and 28A). Waves from east to northeast overtopped the north caisson breakwater and caused adverse wave-action conditions in the harbor (plate 28). Waves from the east also overtopped this section of the breakwater, but did not cause as much disturbance along the coal wharf and in the slips as was caused by northeasterly storms.

35. The results of tests of plan K (plan J plus item 4) are shown on plates 29 and 30. For waves from the northeast the wave absorber, item 4, improved conditions in the slips. Results of tests of plan L (plan K plus item 1) are shown on plate 31. The additional wave absorber, item 1, improved conditions slightly in the slip areas over those of plan K.

36. Observational tests were conducted with items 10, X and 6 installed (plan M) to determine harbor conditions for this series when

overtopping of the north caisson breakwater by northeast waves was eliminated. The item 6 rubble mound practically eliminated all overtopping, and wave-action conditions in the harbor were excellent.

37. Previous tests had shown that, for the series of plans J-O, the south-southeast direction was the most critical with respect to waves entering the harbor through the navigation entrance. Because of this fact, south-southeast waves were the only test condition used for investigating plan N. Conditions in the outer and inner harbor were good with plan N (plate 32) installed. However, adverse conditions obtained in most of the berthing space provided by the Wisconsin Electric Power Co.'s proposed ultimate development (item 11).

38. The results of tests on plan N-1 are shown on plate 33. The deflector arm of item X-A was designed to prevent waves reflected from the vertical-faced coal wharves (item 11) from entering the harbor. Results of tests with waves from the southeast and south-southeast indicated that the deflector arm improved conditions along the entire length of the north face of the north coal wharf. However, the wave deflector might prove to be a navigation hazard.

39. Plate 34 shows that for plan O the heights of waves from the south-southeast were reduced slightly along the north face of the north coal wharf and in the inner harbor. Over-all conditions in the harbor were about the same as those obtained with plan J installed.

Plans P, Q, R, S, T, T-1, T-2, and U

Description of plans

40. This series of plans was similar to plans J-O just described

except that the 2050-ft-long rubble extension of the existing north breakwater (item X) was reduced to 1450 ft (item X-1) to determine the effectiveness of the 600-ft shorter, and therefore less expensive, structure. Removal of the south caisson breakwater (item 10) was also common to plans P-U. Location and alignment of item X-1 are shown on plate 2.

a. Plan P comprised items 10 and X-1 (compare with plan J).

b. Plans Q, R, and S included plan P plus the protective works of items 4, 1, and 6, respectively (similar to plans K, L, and M).

c. Plan T comprised items 10, X-1, and 11 (see plan N).

d. Plan T-1 was plan T with item 6 added.

e. Plan T-2 (see plates 2 and 42) consisted of the elements of plan T-1 plus a 230-ft wave-deflector breakwater installed at the northeast corner of the extended north coal wharf. The addition of this wave deflector to item X-1 was designated item X-1A (similar to plan N-1).

f. Plan U was the same as plan T except that item 11-A was used in plan U instead of item 11 (similar to plan O).

Test results

41. The effects of reducing the length of the item X breakwater (item X-1) are shown by comparing the results of tests on plans P-U with results of tests on plans J-O (compare data for plan P with plan J, K with Q, etc.). In general the item X-1 breakwater extension provided the harbor less protection than the item X breakwater extension.

42. Results of tests of plan P indicate that the plan would provide good protection against waves from the southeast and east (plates 35B and 36A). However, overtopping of the north caisson breakwater by waves from the east (see fig. 10) caused more disturbance in the harbor than waves entering through the navigation opening. Wave-height data (plates 35A and

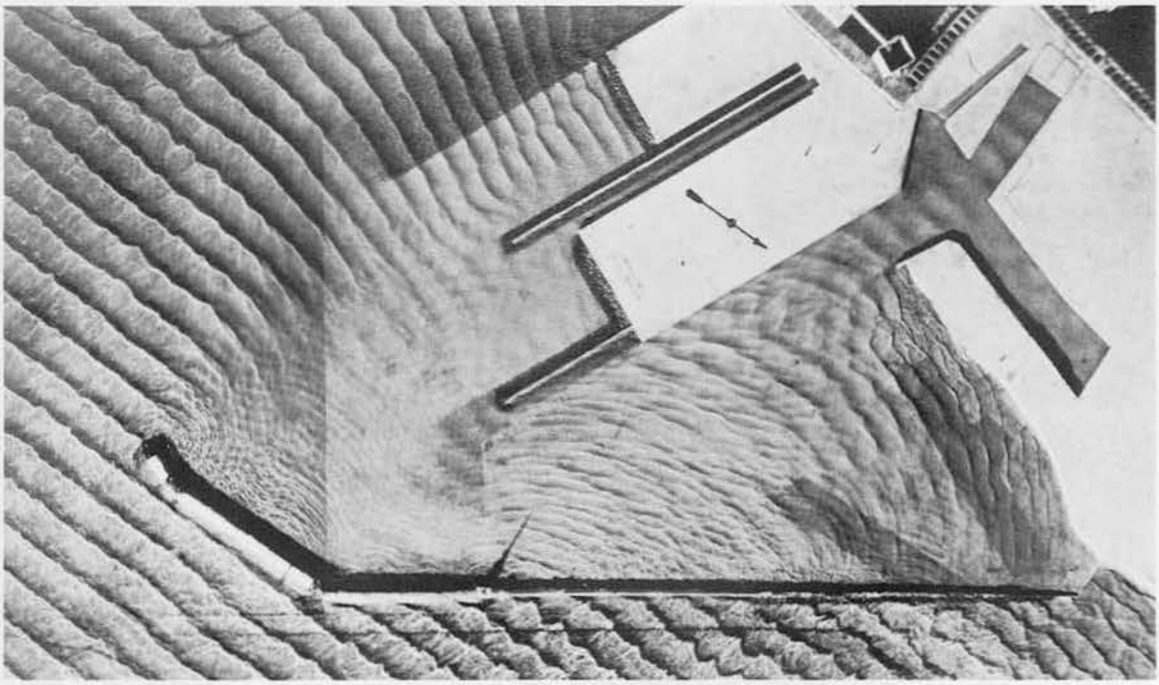


Figure 10. Plan P with 5.5-sec waves 12-ft high from the east

36B) show that plan P would not provide adequate protection against south-southeast and northeast storm waves. For the south-southeast direction the disturbance in the harbor was caused by wave energy which entered the harbor through the navigation opening. The northeast storm waves overtopped the north caisson breakwater. Plans Q and R provided greater reduction of wave action in the slip areas than did plan R owing to addition of item 4 and items 1 and 4 (rubble wave absorbers), respectively. Results of tests on plans Q and R are shown on plates 37, 38, and 39. In tests of plan S, the rubble on the lakeside of the north caisson breakwater (item 6) controlled overtopping effectively (see plate 40).

43. Plan T would not provide adequate protection to the harbor area, nor would it protect the berthing space provided by the expanded harbor facilities (item 11) from south-southeast storms (plate 41). Also, this plan would not protect the north caisson breakwater from overtopping

by northeast waves (see fig. 11). Plan T-1 would provide protection from overtopping by northeast storm waves (see fig. 12). The 230-ft deflector-stub breakwater of plan T-2 provided slightly more protection from storms

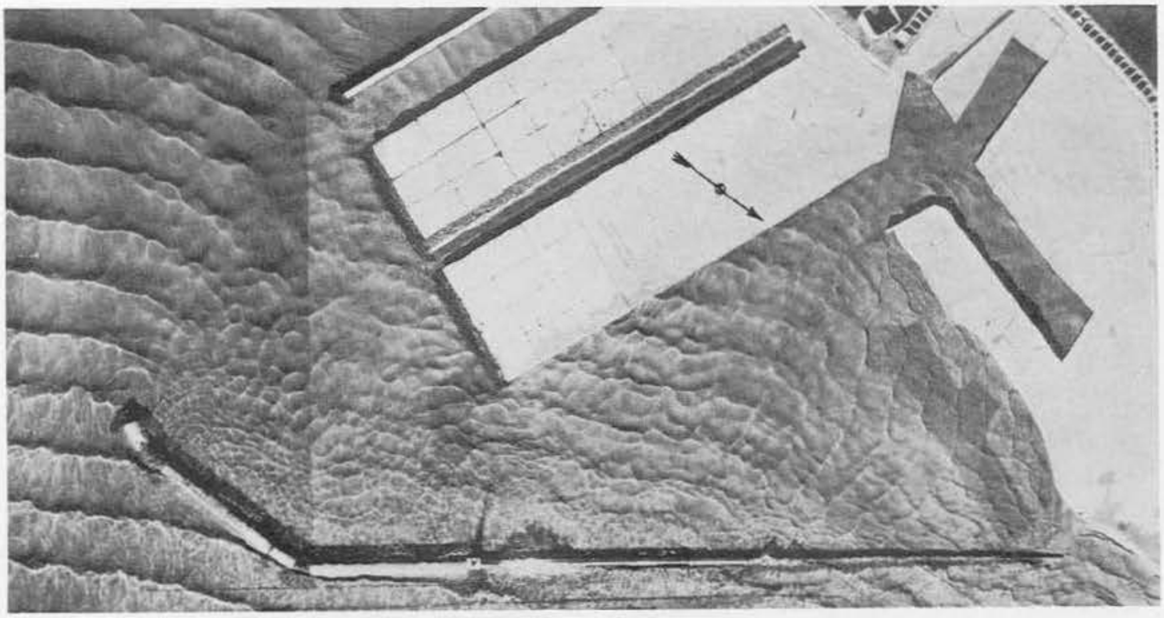


Figure 11. Plan T with 7.5-sec waves 21.0-ft high from the northeast

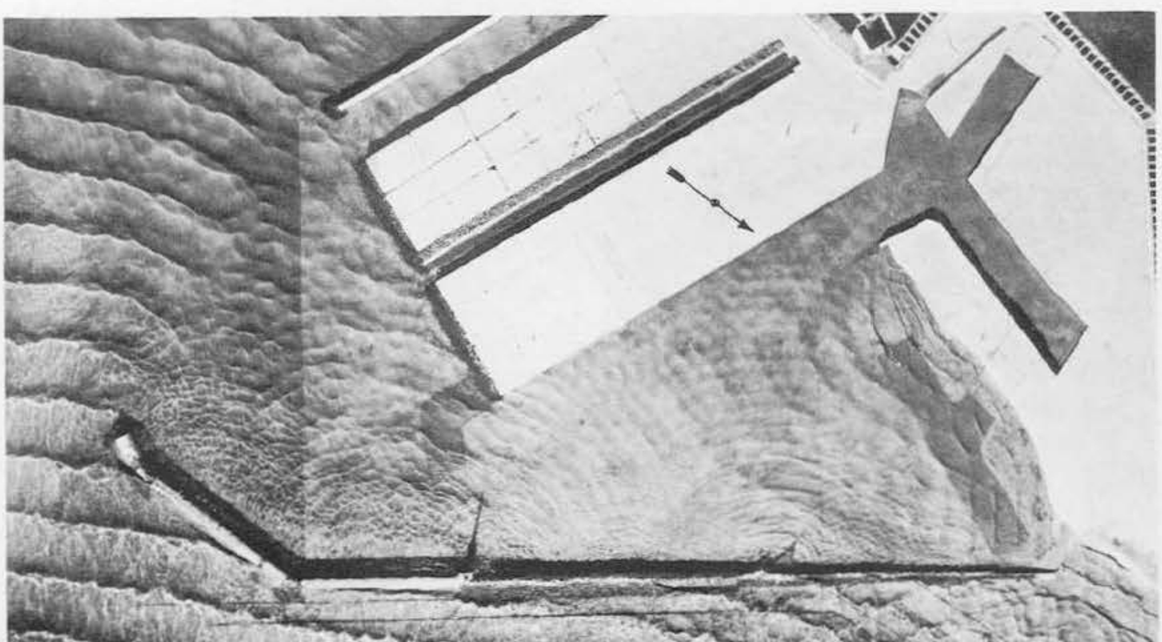


Figure 12. Plan T-1 with 7.5-sec waves 21.0-ft high from the northeast

from the southeast (plate 42) but did not provide adequate protection from south-southeast storms. The 150-ft stub breakwater at the northeast corner of the north coal wharf in plan U (figs. 13 and 14 and

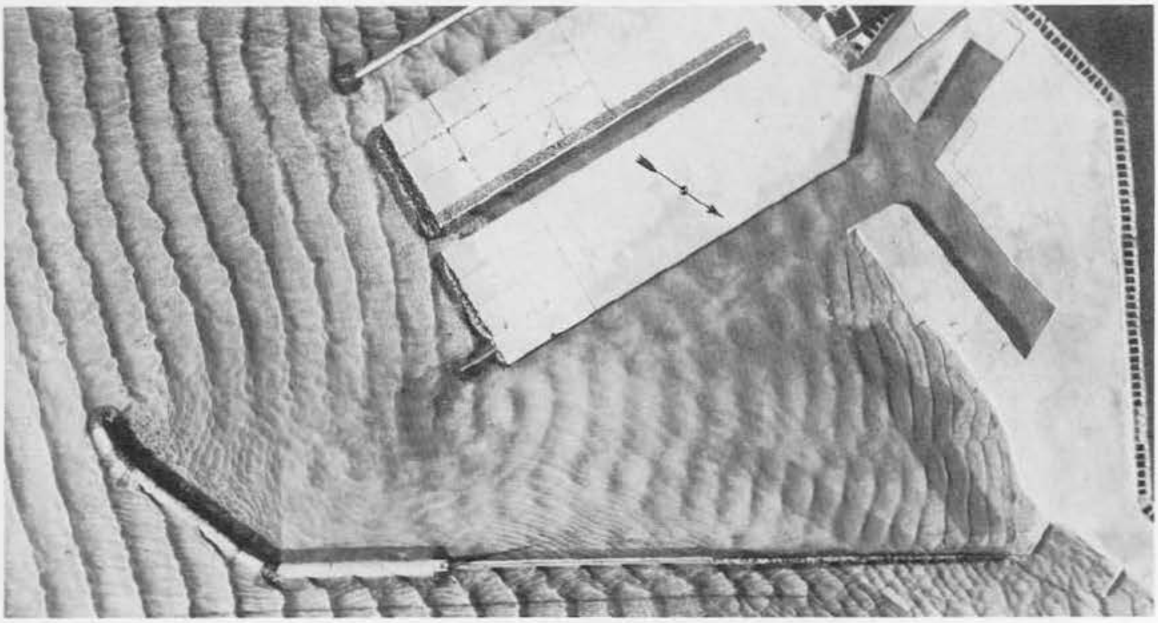


Figure 13. Plan U with 6.0-sec waves 14.5-ft high from the southeast

Figure 14. Plan U with 6.5-sec waves 15.5-ft high from south-southeast

plate 43) would also be inadequate to protect the harbor against storms from the southeast and south-southeast.

Plan V

Description of plan

44. Plan V was designed to reduce to a satisfactory minimum reflections from the harbor side of the north caisson breakwater. It consisted of the item X-1 breakwater extension, 700 ft of rubble mound on the harbor side of the north caisson breakwater (item 6-A), and removal of the south caisson breakwater (item 10). Items 10 and X-1 are common to plan V and plans P through U.

Test results

45. Plate 44 and figures 15 and 16 show that the combination of the item X-1 breakwater and the item 6-A rubble wave absorber inside the harbor would provide satisfactory conditions along the coal wharf and in the slip areas for waves from the southeast and south-southeast. Plan V would not provide the harbor adequate protection against northeasterly storms unless item 6 were added to the elements of this plan.

Plan W

Description of plan

46. Plan W was a modification of plan P (items 10 and X-1). The difference between these plans was the alignment of the terminal section of item X-1, a 170-ft length of curved breakwater. This section was realigned to the alignment of the north-south breakwater arm, to which the curved section was tangent. This modification was designated item

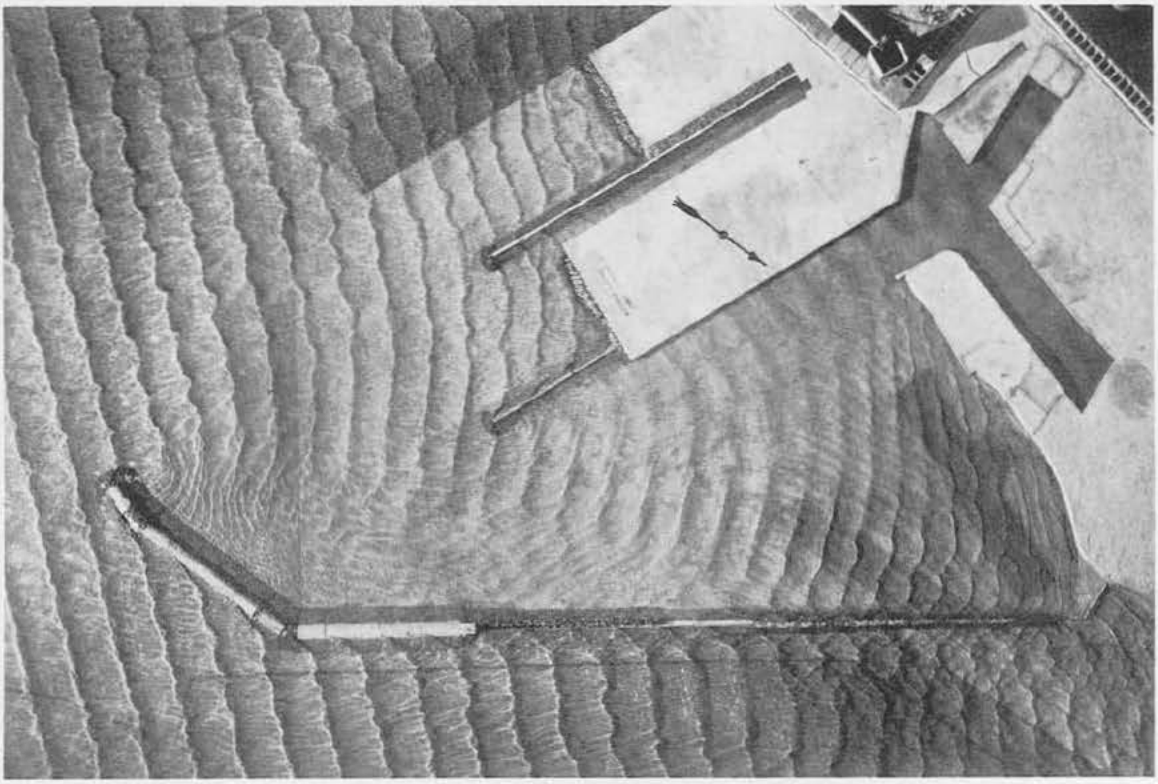


Figure 15. Plan V with 6.0-sec waves 14.5-ft high from the southeast

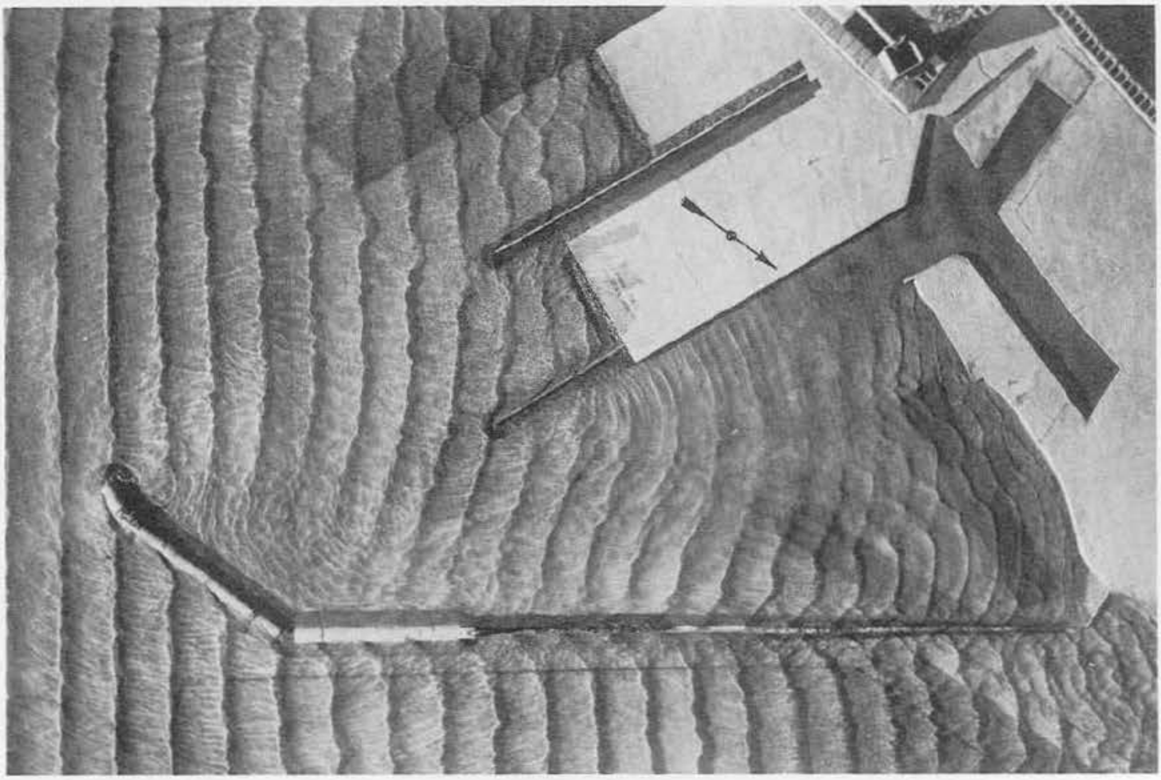


Figure 16. Plan V with 6.5-sec waves 15.5-ft high from south-southeast

X-2. The elements of plan W are shown on plates 2 and 45.

Test results

47. Wave-height data shown on plate 45 indicate that plan W would be inadequate to protect the harbor against waves from the south-southeast. On the basis of results of tests on plan P, the elements of which are very similar to those of plan W, it is believed that plan W would provide good protection against southeast and east storms. Plan W would be inadequate for protection against northeast storms.

Plans Y and Z

Description of plans

48. These plans were proposed to provide more space at the navigation entrance for the convenience of shipping. This was effected by shortening the item X breakwater extension by 770 ft (item X-3). Item X-3 was also 170 ft shorter than the lakeward terminus of item X-2. Thus the plans included two very desirable features: first, only 1280 ft of new breakwater was involved compared with 2050 ft for plans J-N; and second, ships entering and leaving the harbor would be required to navigate a less tortuous route. Plan Y consisted of items X-3 and 10. Plan Z comprised plan Y plus item 6-A and was also similar to plan V.

Test results

49. Figures 17 and 18 show conditions in the harbor with plan Y installed. The data on plate 46A indicate that plan Y would be less effective than plan W against south-southeast storms. Wave heights along the coal wharf and in the inner harbor were slightly greater with plan Y installed than with base-test conditions. With waves from the southeast

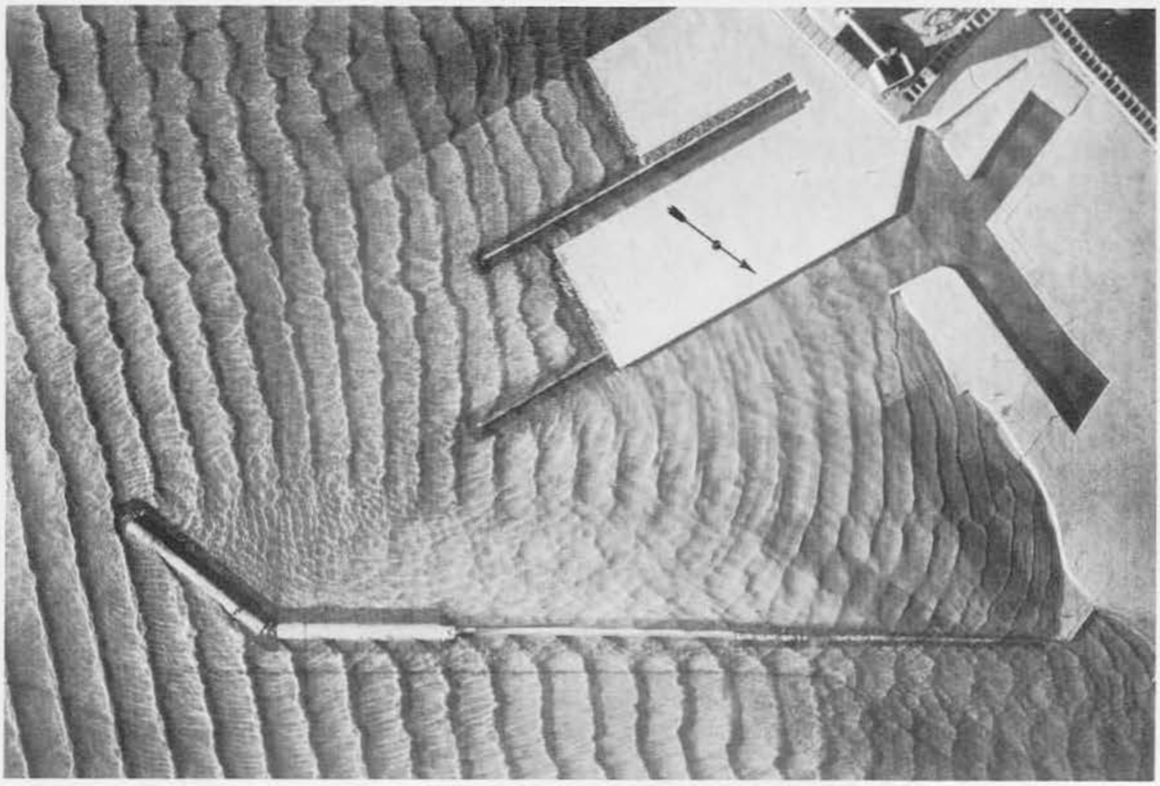


Figure 17. Plan Y with 6.0-sec waves 14.5-ft high from the southeast

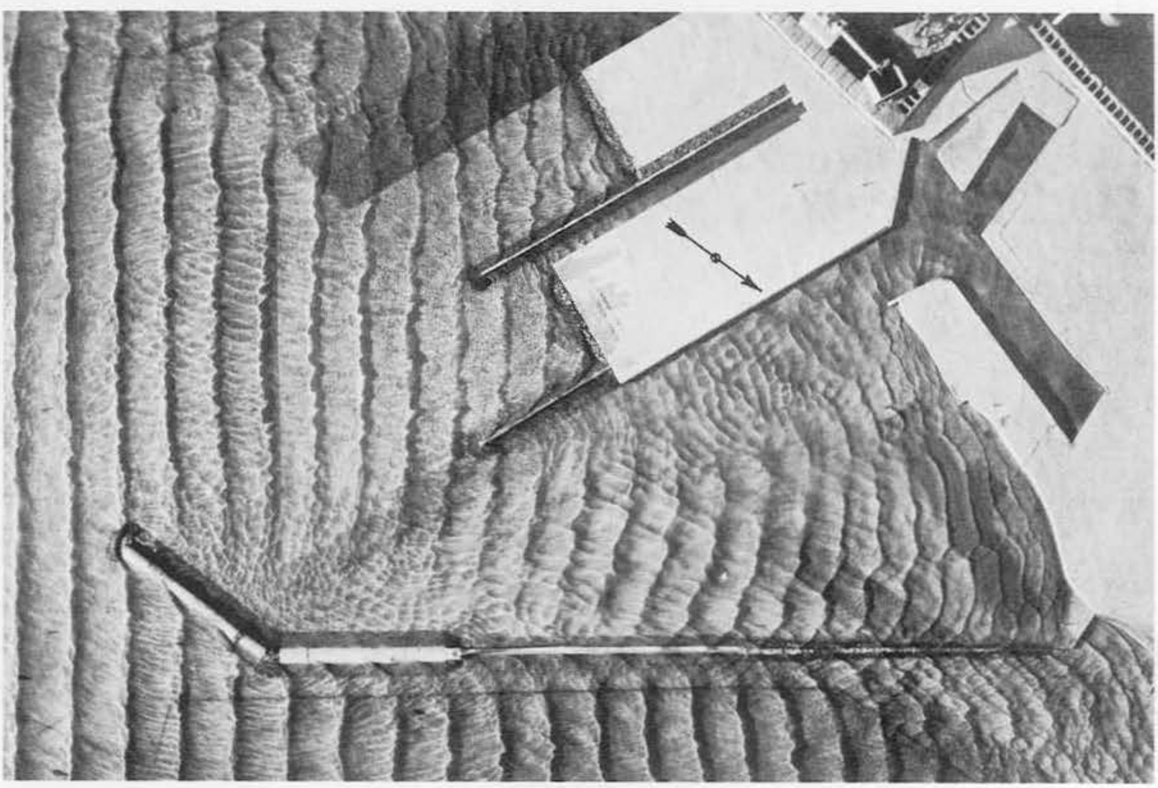


Figure 18. Plan Y with 6.5-sec waves 15.5-ft high from south-southeast

(plate 46B) plan Y was nearly as efficient as plan P.

50. Wave heights with plan Z installed are shown on plate 47. Although plan Z was not as effective as some of the more expensive plans, the reduction of wave heights afforded by this plan is considered adequate except for waves from the northeast. The addition of item 6 to the elements of plan Z would be required to protect the north caisson breakwater from overtopping by northeasterly storm waves. Comparisons of figures 17 and 18 with figures 19 and 20, respectively, show the benefits to be obtained by placing the item 6-A rubble on the harbor side of the north caisson breakwater.

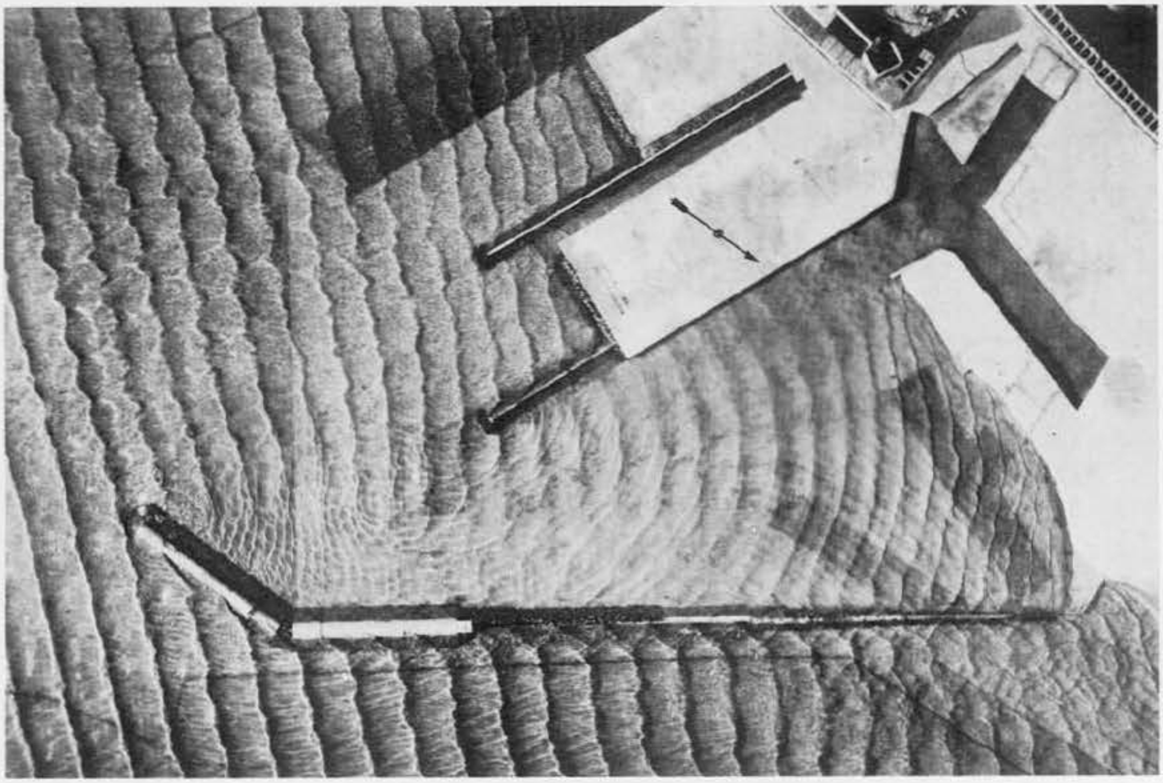


Figure 19. Plan Z with 6.0-sec waves 14.5-ft high from the southeast

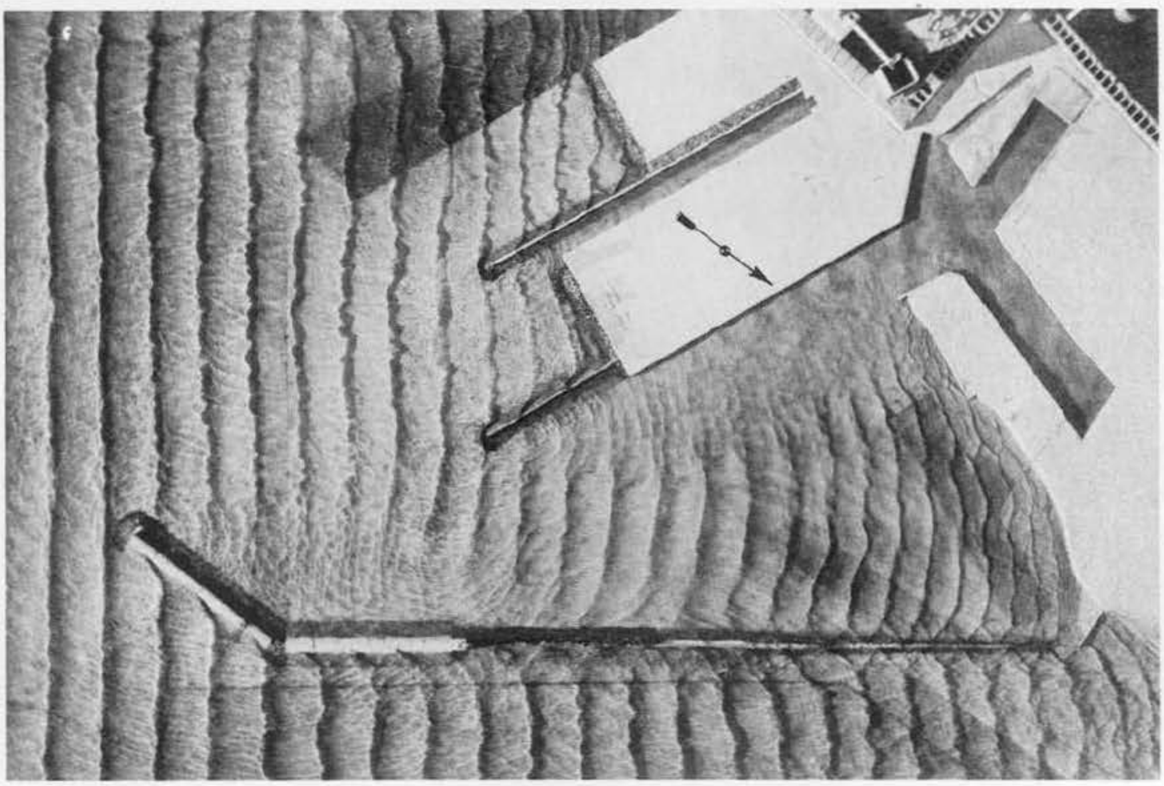


Figure 20. Plan Z with 6.5-sec waves 15.5-ft high from south-southeast

PART V: CONCLUSIONS

51. It is concluded, from an analysis of the model test results, that:

- a. Improvement plans which involve the installation of various harbor works in combination with the existing breakwater system (plans A-F) would not provide adequate protection to the harbor from storm-wave action. Wave absorbers in the slips, and rubble along the lakeside of the north and south caisson breakwaters would improve conditions in the slips and in the outer harbor, but would not provide sufficient improvement of wave-action conditions at the harbor entrance and along the coal wharf.

- b. The small-boat harbors, items 5 and 12, would be satisfactory with respect to wave action.

- c. The wave-deflector stub-type breakwater, item 13, would not provide sufficient added protection to the small-boat harbor (item 12) to justify its construction.

- d. The expanded outer harbor facilities proposed by the Wisconsin Electric Power Co., items 11 and 11-A, could not be utilized except during calm weather. These additional harbor facilities would not be adequately protected from wave action by any of the plans tested.

- e. Plans G, H and I would improve harbor conditions for easterly and northeasterly storms, but for southeasterly storms they would be inadequate because of the amount of wave energy which could enter the harbor through the navigation opening.

- f. The item X breakwater extension, the primary element of plans J-O, would provide better over-all protection to the harbor than any of the other breakwater systems tested. On the other hand, this system would involve the construction of considerable length of new breakwater, and navigation would be hazardous for ships passing through the harbor entrance during southeasterly storms.

- g. All plans of improvement which involve the item X breakwater (or modifications thereof) would require the addition of rubble on the lakeside of the north caisson breakwater (item 6) for control of overtopping by northeasterly storms.

h. The item X-1 breakwater, the primary element of plans P-U, would satisfactorily protect the harbor from all storm directions except south-southeast. This breakwater system is 600 ft shorter than the item X breakwater. Although the shorter breakwater would permit more wave energy to enter the harbor, the item X-1 harbor entrance would be less hazardous to navigation.

i. Plan V, similar to plans P-U except that it included item 6-A, would provide the harbor good protection from storms from all directions except northeast. The addition of item 6 to the elements of this plan would insure adequate protection against overtopping during northeasterly storms.

j. Plan Z would provide sufficient protection from waves from all directions if item 6 were added to its elements, and would cost less to construct than any of the other plans tested which could be considered adequate for the purpose desired. Navigation conditions at the entrance would be satisfactory.

TABLES

Table 1

DESCRIPTION OF ITEMS TESTED

Item No.	Description of Item
1	Rubble wave absorber at west end of west slip.
2	Rubble wave absorber at north end of north slip.
3	Rubble wave absorber on pier head between Sauk River and west slip.
4	Rubble wave absorber at junction of north and west slips.
5	Small-boat basin with access channel from north slip.
6	Rubble mound on lakeside of north caisson breakwater.
6-A	Rubble mound on harbor side of north caisson breakwater.
7	Rubble mound on lakeside of south caisson breakwater.
8	North breakwater extended 1200 ft lakeward (rubble construction).
9	Detached south breakwater (rubble-mound structure 1000 ft long).
10	Removal of south caisson breakwater to a depth of -22 ft lwd.
11	Wisconsin Electric Power Company coal wharf extensions, ship channel and combination rubble breakwater and pier.
11-A	Lengths of all item 11 elements shortened 150 ft.
12	Small-boat harbor north of north breakwater with access channel from outer harbor.
13	Rubble-mound wave-deflector stub on harbor side of north breakwater.
X	North breakwater extended 2050 ft lakeward (rubble construction).
X-A	North breakwater extended 2050 ft lakeward (item X) plus a 230-ft wave deflector at northeast corner of north coal wharf extended.

Table 1 (Cont'd)

Item No.	Description of Item
X-1	North breakwater extended 1450 ft lakeward (rubble construction, terminal section curved).
X-1A	North breakwater extended 1450 ft lakeward (item X-1) plus a 230-ft wave deflector at the northeast corner of the north coal wharf extended.
X-2	North breakwater extended 1450 ft lakeward (rubble construction, terminal section straight).
X-3	North breakwater extended 1280 ft lakeward (rubble construction).

Table 2

LIST OF IMPROVEMENT PLANS TESTED AND PLATE INDEX

Plan	Elements of Plan (Items Added to Basic Harbor Elements)	Reference Plate Numbers for Plans and Wave Directions Tested							
		SSE	SE	S60°E	S75°E	E	N75°E	N60°E	NE
Base Test	None	3A	3B	4A	4B	5A	5B	6A	6B
A	6 & 7	7A	7B	8A	8B	9A	9B	10A	10B
B	1 & 4	11A	11B	x	x	12A	x	x	12B
C	1, 2, 3 and 4	13A	13B	x	x	14A	x	x	14B
D	1, 2, 4 and 5	15A	15B	x	x	16A	x	x	16B
E	1, 4, 6, 7, 12 & 13	17A	17B	x	x	18A	x	x	18B
E-1	1, 4, 6, 7 and 12	x	*	x	x	x	x	x	x
F	1, 2, 3, 4, 6, 7 & 11	19A	19B	x	x	20A	x	x	20B
G	1, 4, 6, 8, 9 & 10	21A	21B	x	x	*	x	x	*
H	6, 8, 9, 10, 12 & 13	22	*	x	x	23A	x	x	23B
I	6, 8, 9, 10 & 11	24	25A	25B	x	26A	x	x	26B
J	10 and X	27A	27B	x	x	28A	x	x	28B
K	10, 4 and X	29	x	x	x	30A	x	x	30B
L	10, 1, 4 and X	31	x	x	x	x	x	x	x
M	10, 6 and X	x	x	x	x	x	x	x	*
N	10, 11 and X	32	x	x	x	x	x	x	x
N-1	10, 11 and X-A	33A	33B	x	x	x	x	x	x
O	10, 11-A and X	34	x	x	x	x	x	x	x
P	10 and X-1	35A	35B	x	x	36A	x	x	36B
Q	10, 4 and X-1	37A	37B	x	x	38A	x	x	38B
R	10, 1, 4 and X-1	39	x	x	x	x	x	x	x

Table 2 (Cont'd)

Plan	Elements of Plan (Items Added to Basic Harbor Elements)	Reference Plate Numbers for Plans and Wave Directions Tested							
		SSE	SE	S60°E	S75°E	E	N75°E	N60°E	NE
S	10, 6 and X-1	x	x	x	x	x	x	x	40
T	10, 11 and X-1	41	x	x	x	x	x	x	*
T-1	10, 11, 6 and X-1	x	x	x	x	x	x	x	*
T-2	10, 11, 6 and X-1A	*	42	x	x	x	x	x	x
U	10, 11-A and X-1	43	*	x	x	x	x	x	x
V	10, 6-A and X-1	44	*	x	x	x	x	x	x
W	10 and X-2	45	x	x	x	x	x	x	x
Y	10 and X-3	46A	46B	x	x	x	x	x	x
Z	10, 6-A and X-3	47A	47B	x	x	x	x	x	x

* Denotes observational tests.

x Tests omitted.

PLATES

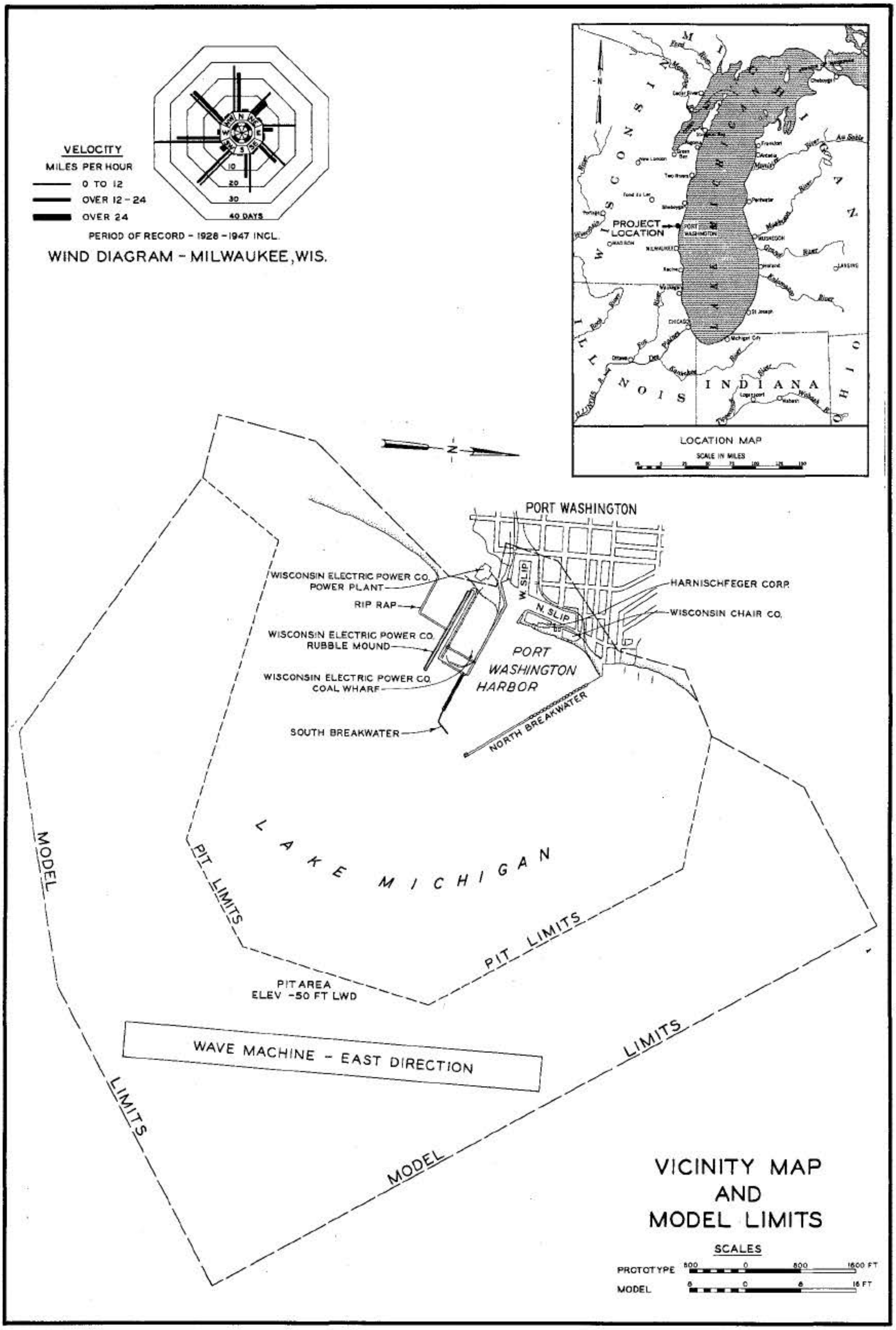
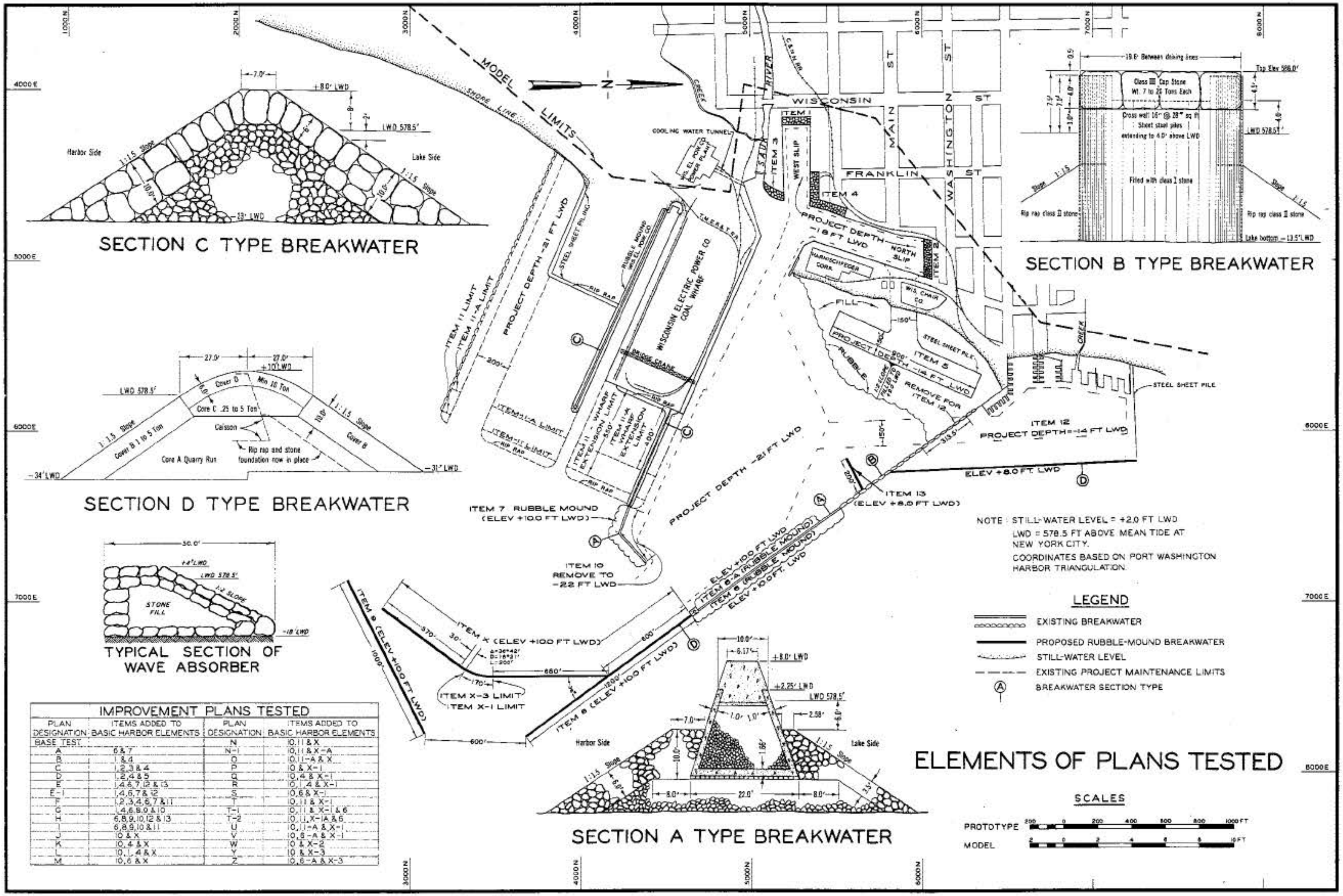

VELOCITY
MILES PER HOUR
0 TO 12
OVER 12 - 24
OVER 24
10
20
30
40 DAYS
PERIOD OF RECORD - 1928 - 1947 INCL.
WIND DIAGRAM - MILWAUKEE, WIS.
PROJECT LOCATION
WISCONSIN
ILLINOIS
INDIANA
LAKE MICHIGAN
LOCATION MAP
SCALE IN MILES
N
PORT WASHINGTON
WISCONSIN ELECTRIC POWER CO. POWER PLANT
RIP RAP
WISCONSIN ELECTRIC POWER CO. RUBBLE MOUND
WISCONSIN ELECTRIC POWER CO. COAL WHARF
SOUTH BREAKWATER
W. SLIP
N. SLIP
HARNISCHFEGER CORP.
WISCONSIN CHAIR CO.
PORT WASHINGTON HARBOR
NORTH BREAKWATER
LAKE MICHIGAN
PIT LIMITS
PIT LIMITS
PIT AREA
ELEV -50 FT LWD
WAVE MACHINE - EAST DIRECTION
MODEL LIMITS
MODEL LIMITS
VICINITY MAP
AND
MODEL LIMITS
SCALES
PROTOTYPE 800 0 800 1600 FT
MODEL 8 0 8 16 FT

PLATE 1



IMPROVEMENT PLANS TESTED

PLAN DESIGNATION	ITEMS ADDED TO BASIC HARBOR ELEMENTS	PLAN DESIGNATION	ITEMS ADDED TO BASIC HARBOR ELEMENTS
BASE TEST		N	10, 11 & X
A	6 & 7	N-1	10, 11 & X-A
B	1 & 4	O	10, 11-A & X
C	1, 2, 3 & 4	P	10 & X-1
D	1, 2, 4 & 5	Q	10, 4 & X-1
E	1, 4, 6, 7, 12 & 13	R	10, 1, 4 & X-1
E-1	1, 4, 6, 7 & 12	S	10, 6 & X-1
F	1, 2, 3, 4, 6, 7 & 11	T	10, 11 & X-1
G	1, 4, 6, 8, 9 & 10	T-1	10, 11 & X-1 & 6
H	6, 8, 9, 10, 12 & 13	T-2	10, 11, X-1A & 6
I	6, 8, 9, 10 & 11	U	10, 11-A & X-1
J	10 & X	V	10, 6-A & X-1
K	10, 4 & X	W	10 & X-2
L	10, 1, 4 & X	Y	10 & X-3
M	10, 6 & X	Z	10, 6-A & X-3

PLATE 2

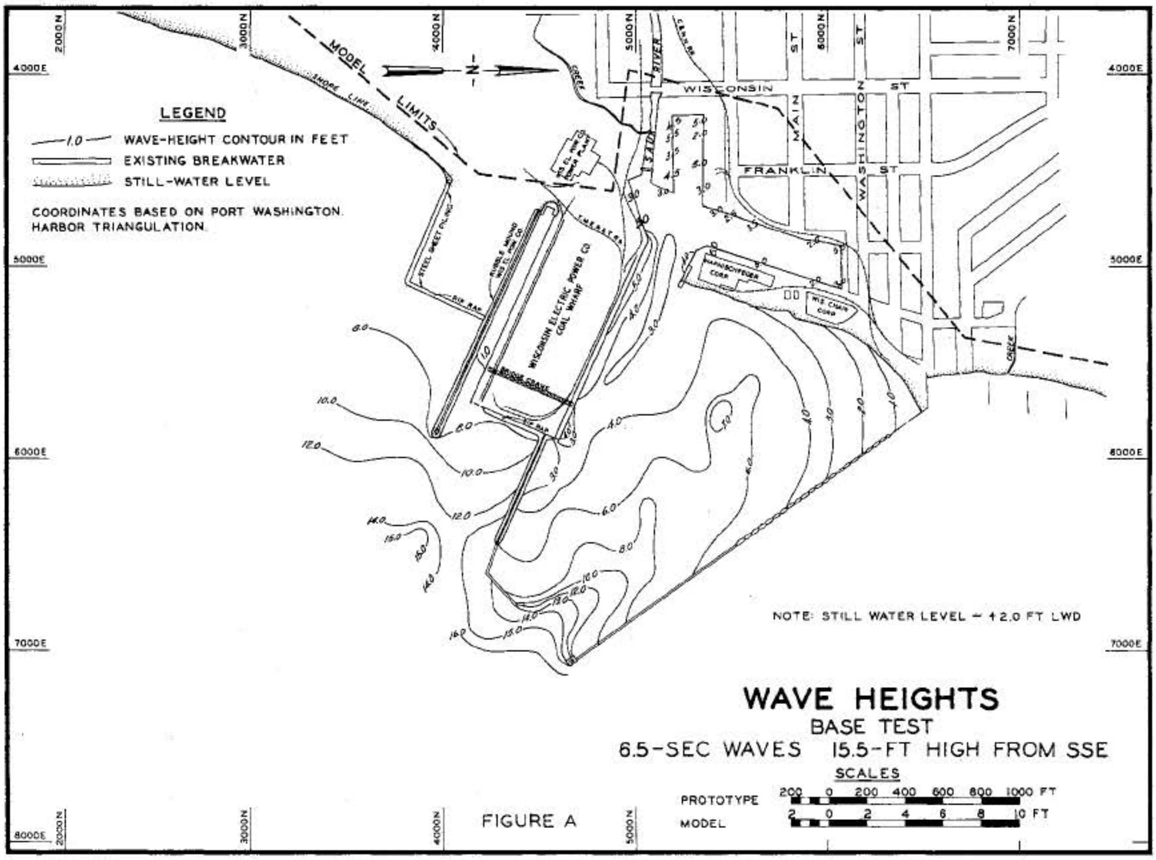


FIGURE A

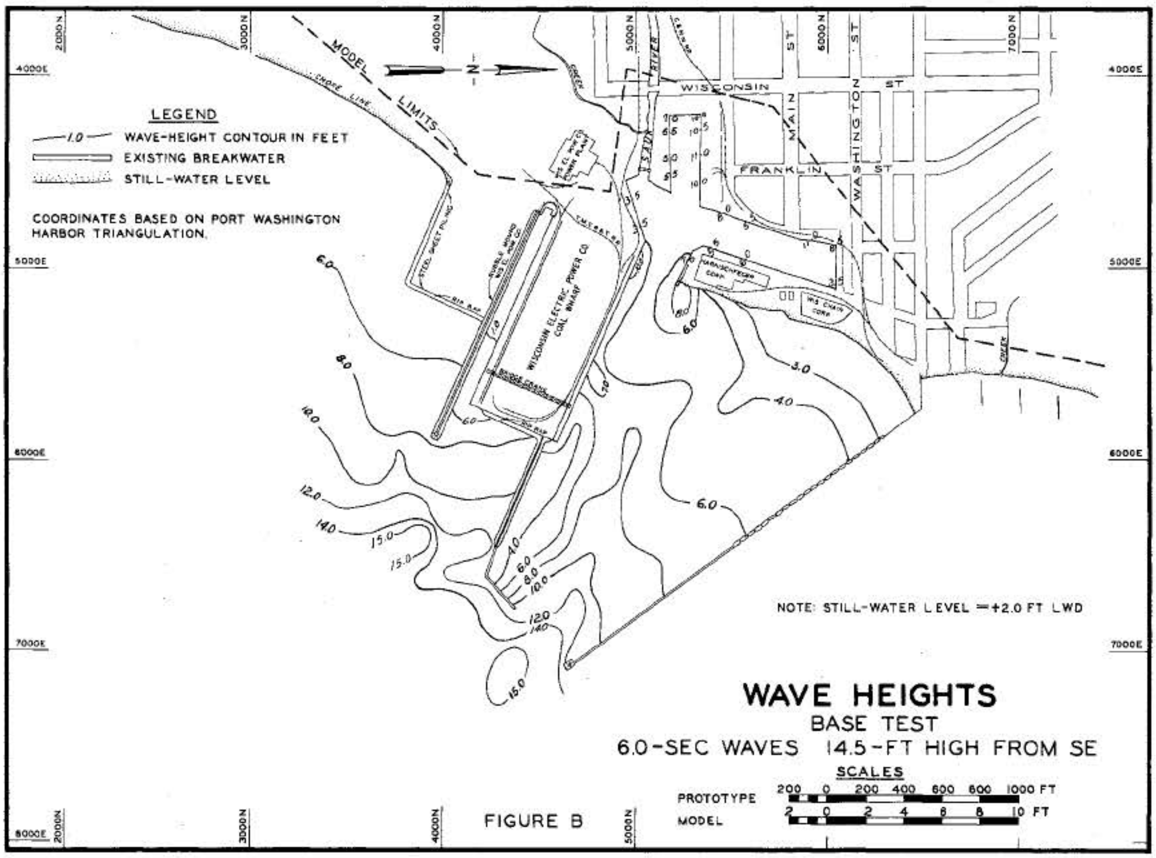
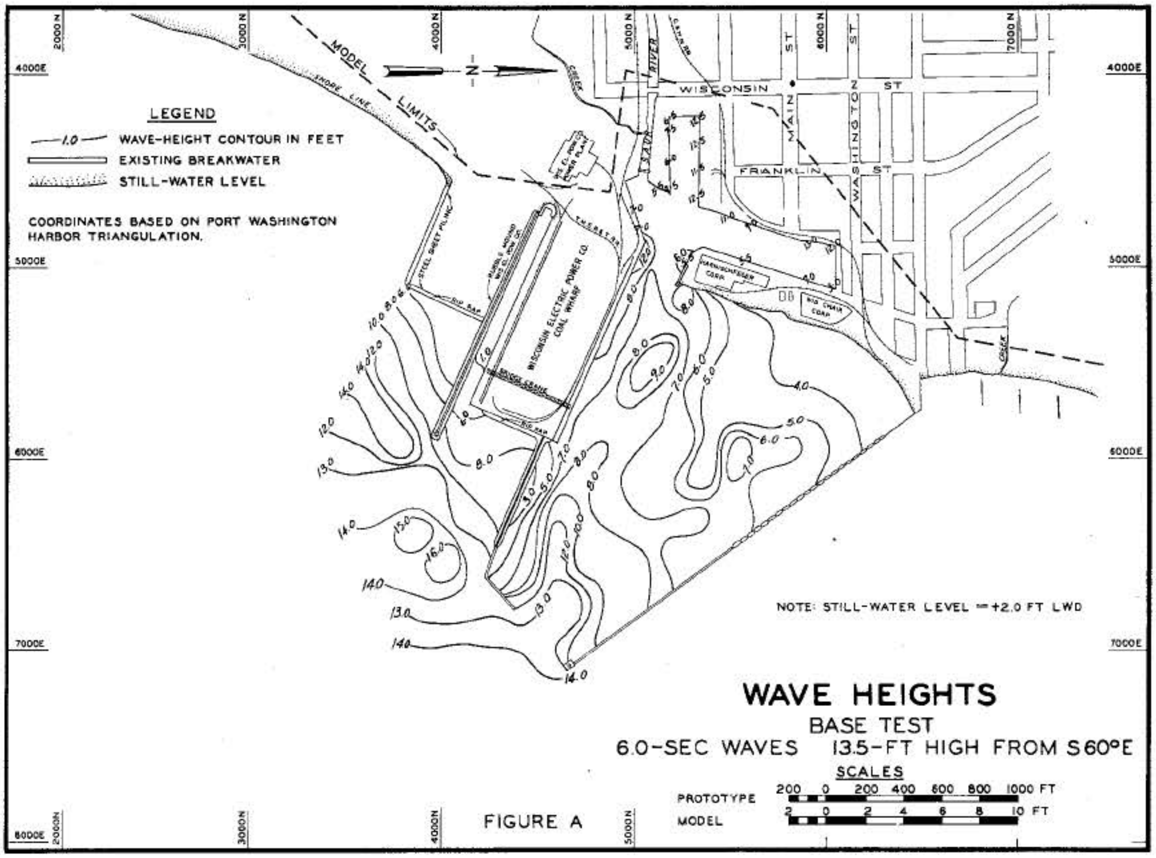


FIGURE B

PLATE 3

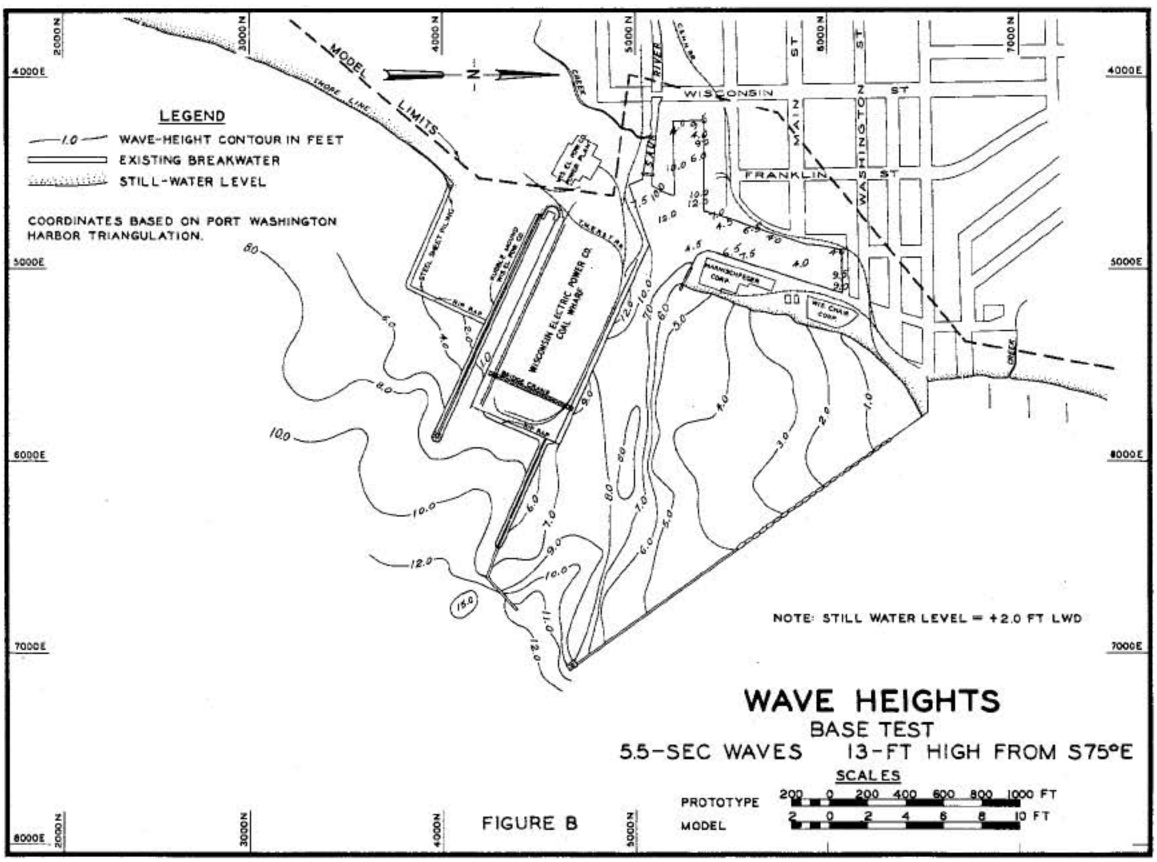


WAVE HEIGHTS

BASE TEST

6.0-SEC WAVES 13.5-FT HIGH FROM S60°E

FIGURE A

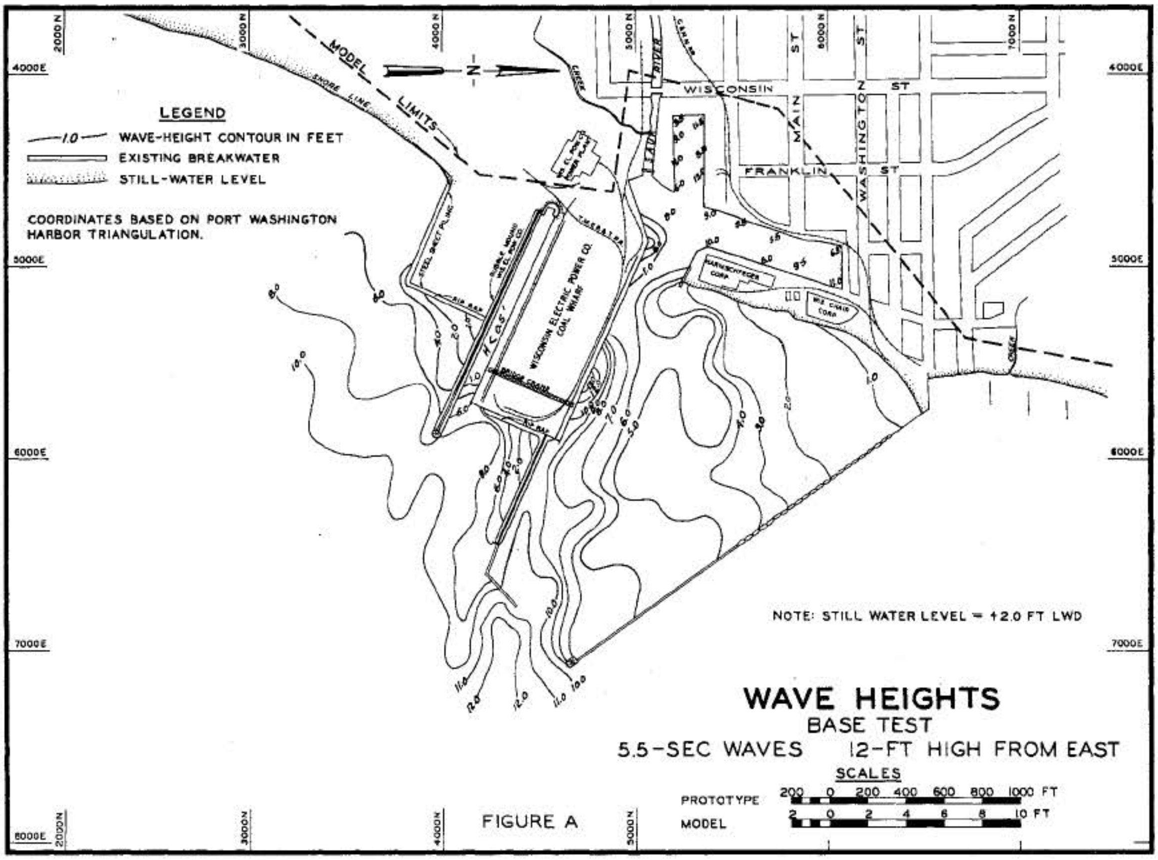


WAVE HEIGHTS

BASE TEST

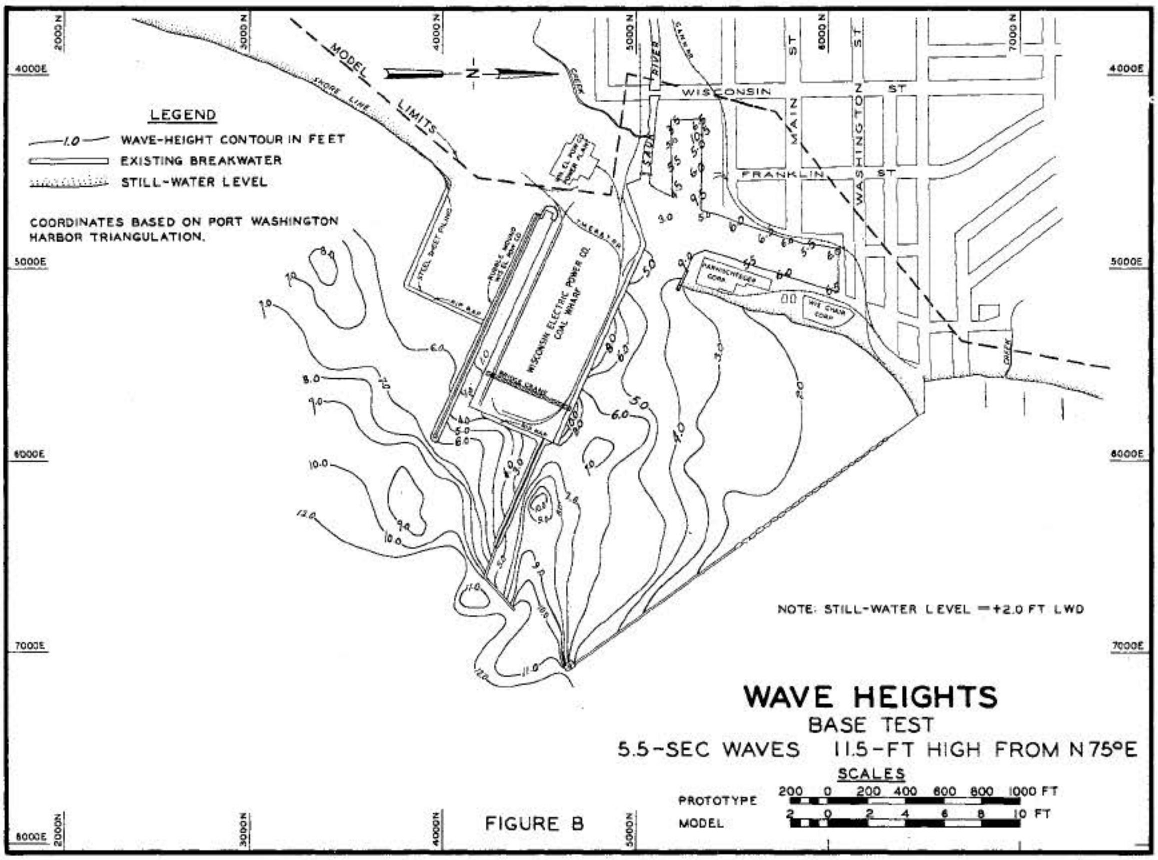
5.5-SEC WAVES 13-FT HIGH FROM S75°E

FIGURE B



WAVE HEIGHTS
BASE TEST
5.5-SEC WAVES 12-FT HIGH FROM EAST

FIGURE A



WAVE HEIGHTS
BASE TEST
5.5-SEC WAVES 11.5-FT HIGH FROM N 75°E

FIGURE B

PLATE 5

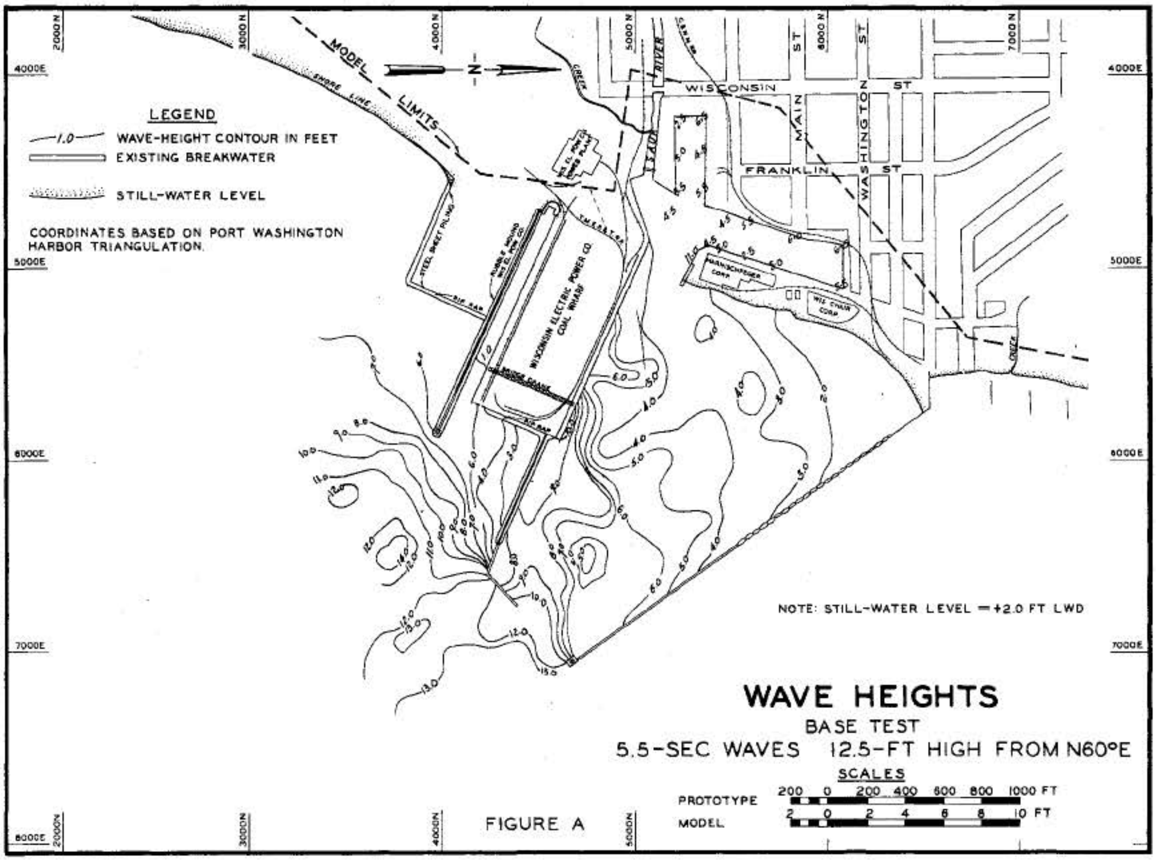


FIGURE A

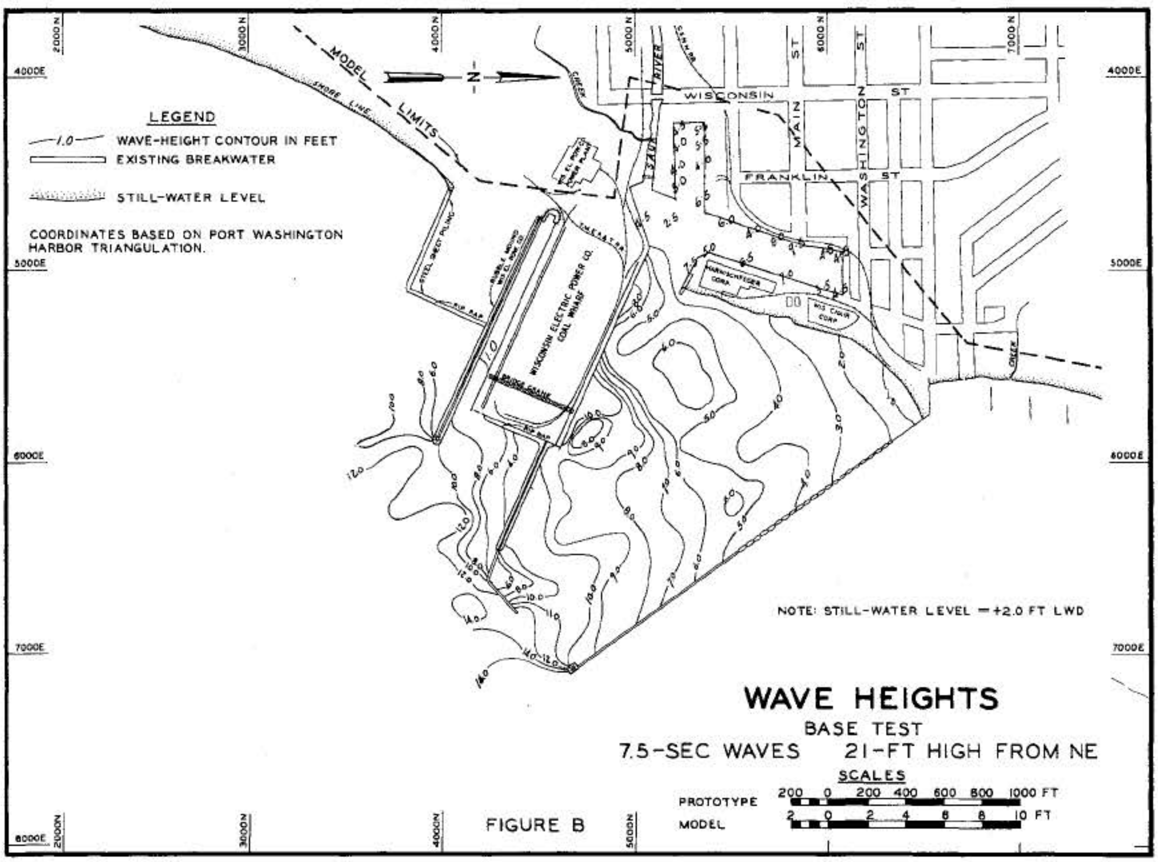


FIGURE B

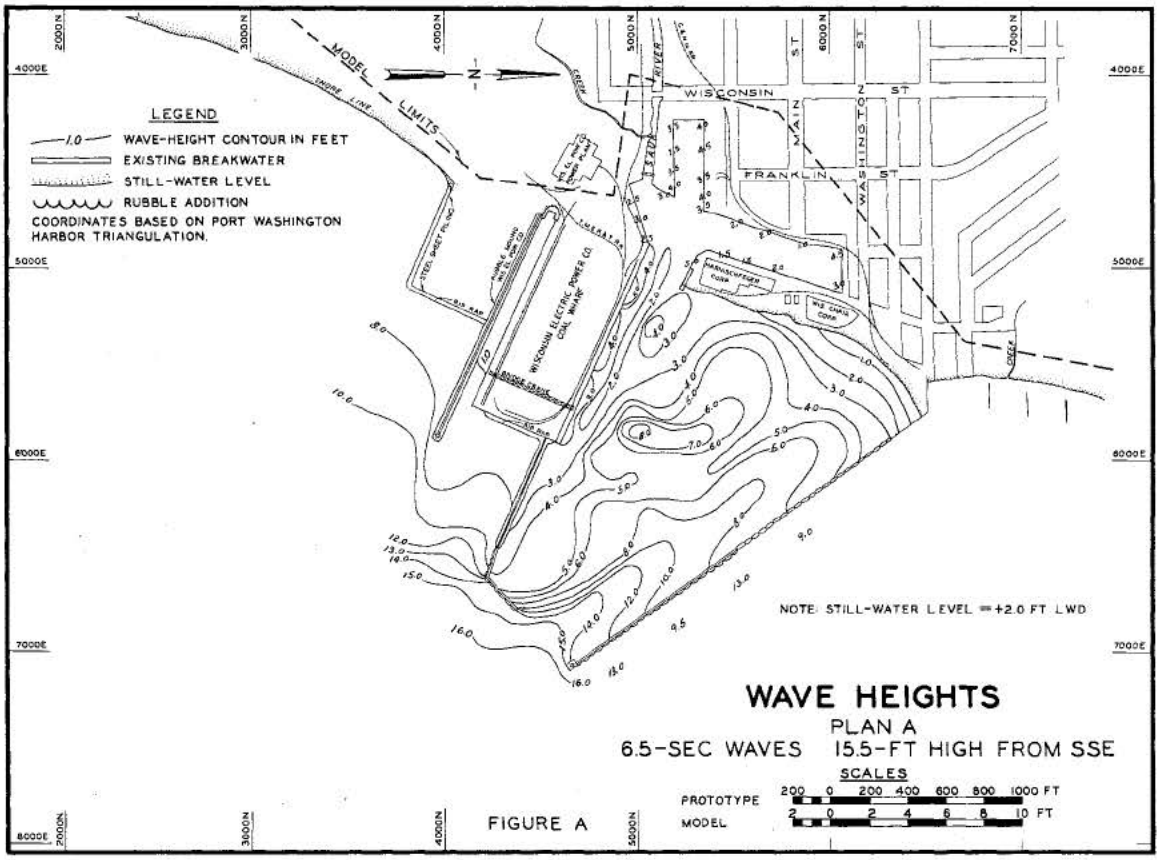


FIGURE A

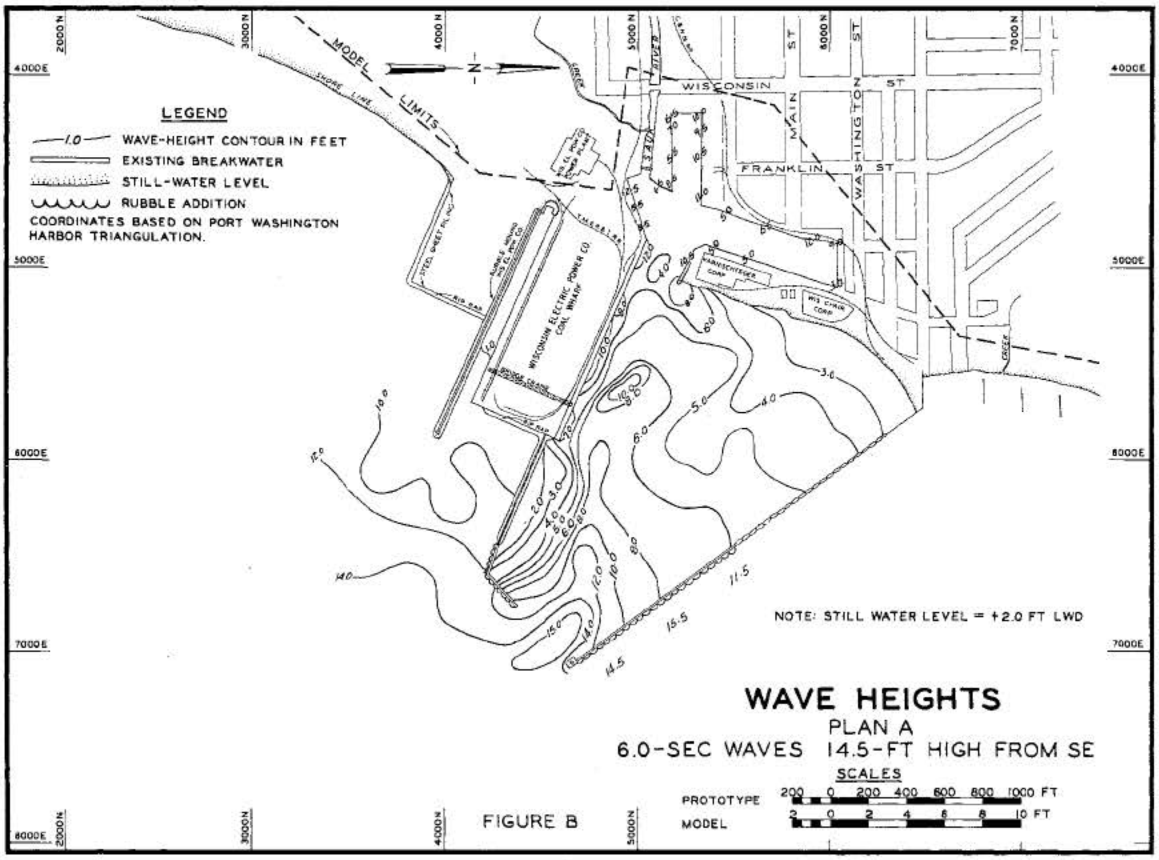


FIGURE B

PLATE 7

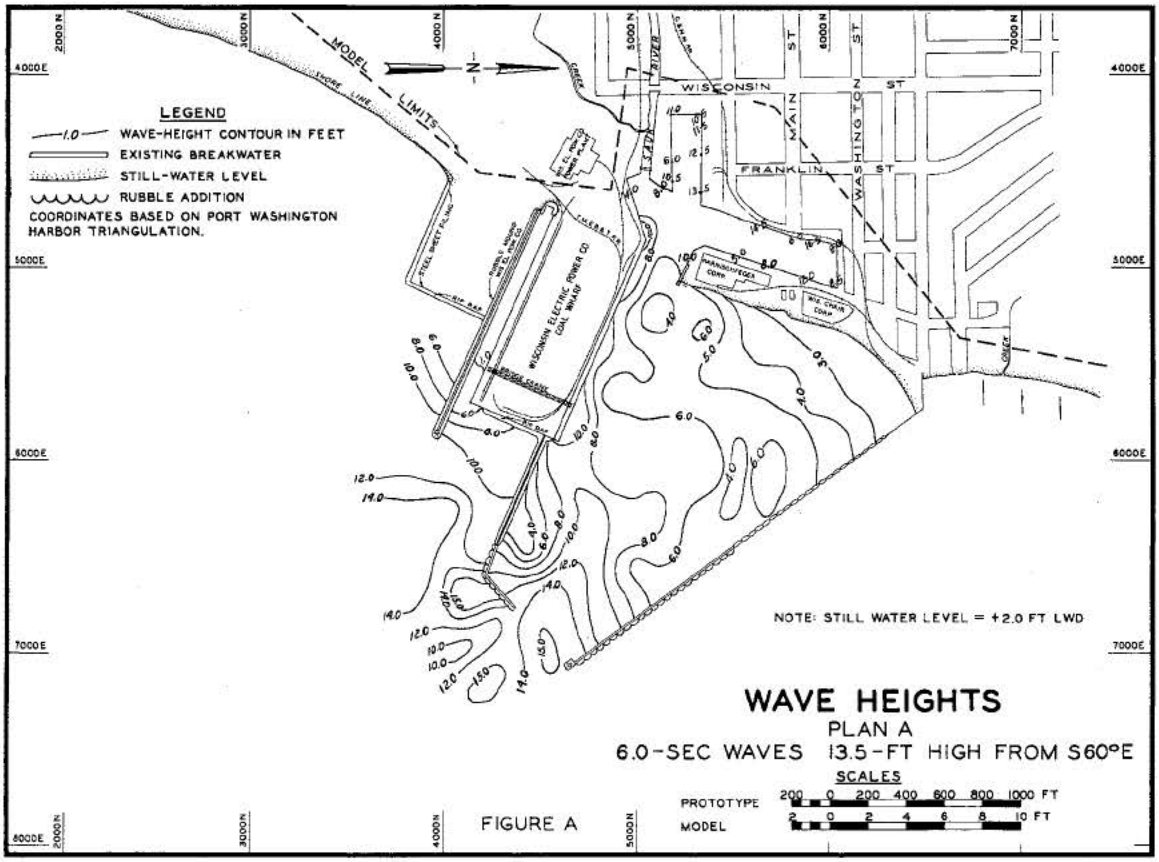


FIGURE A

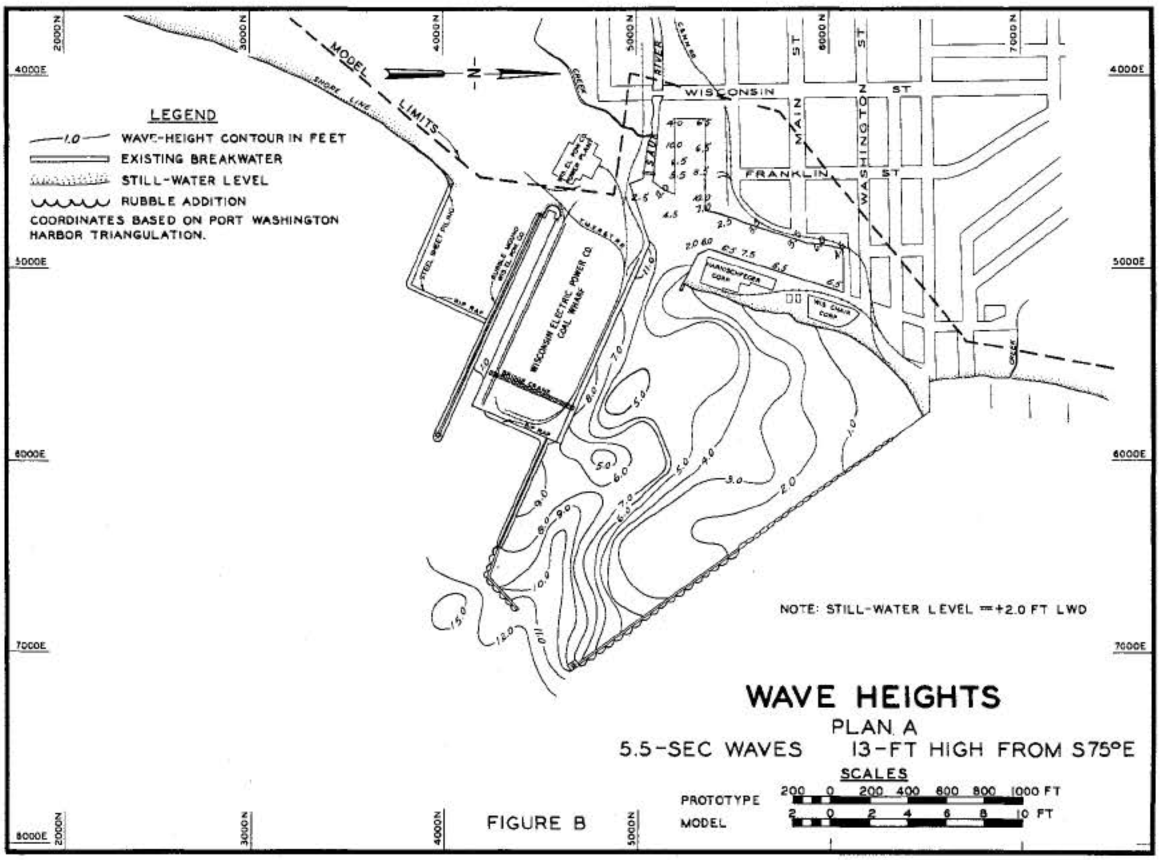


FIGURE B

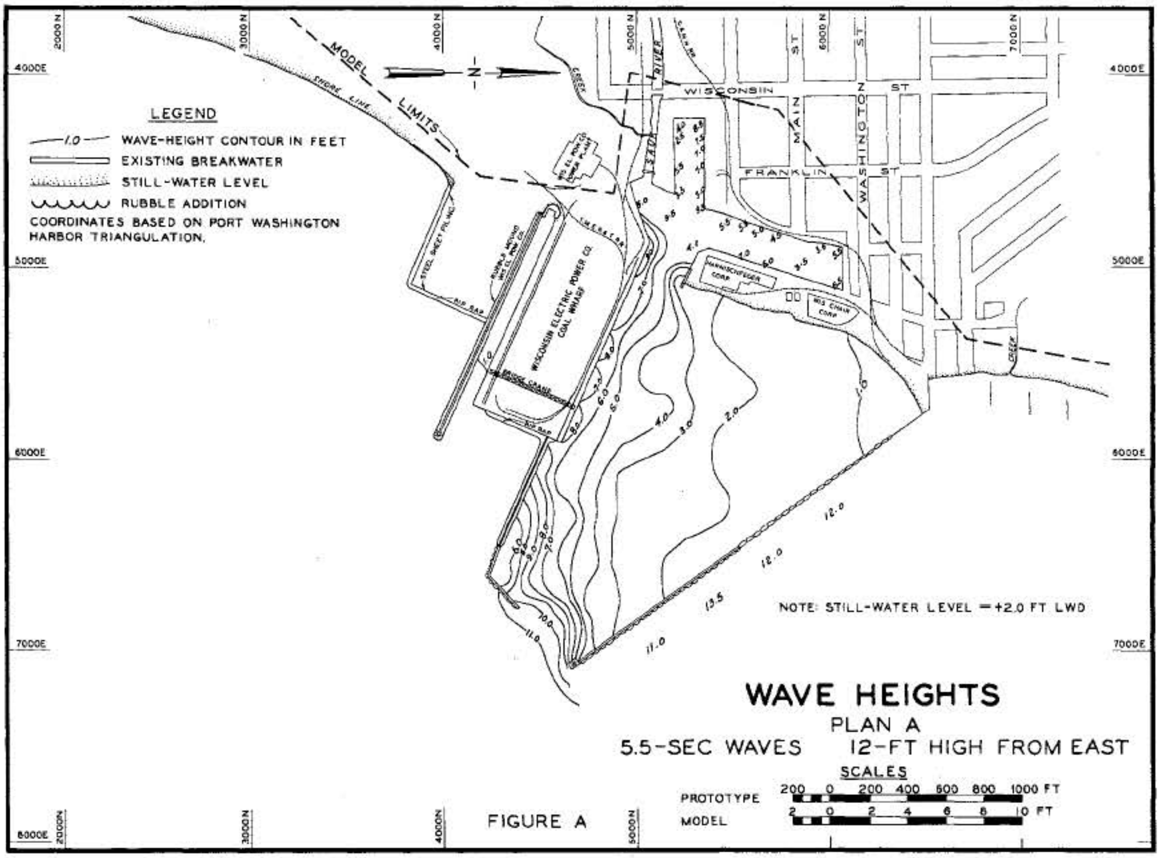


FIGURE A

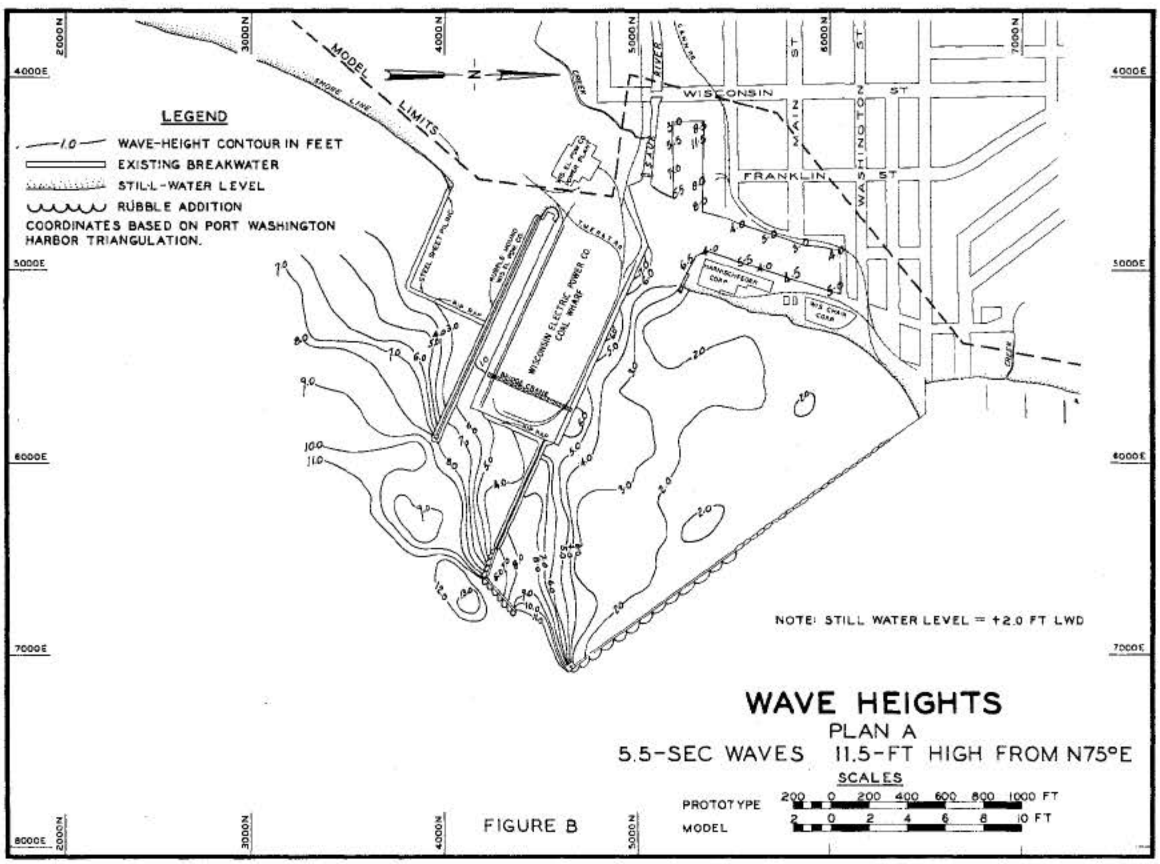


FIGURE B

PLATE 9

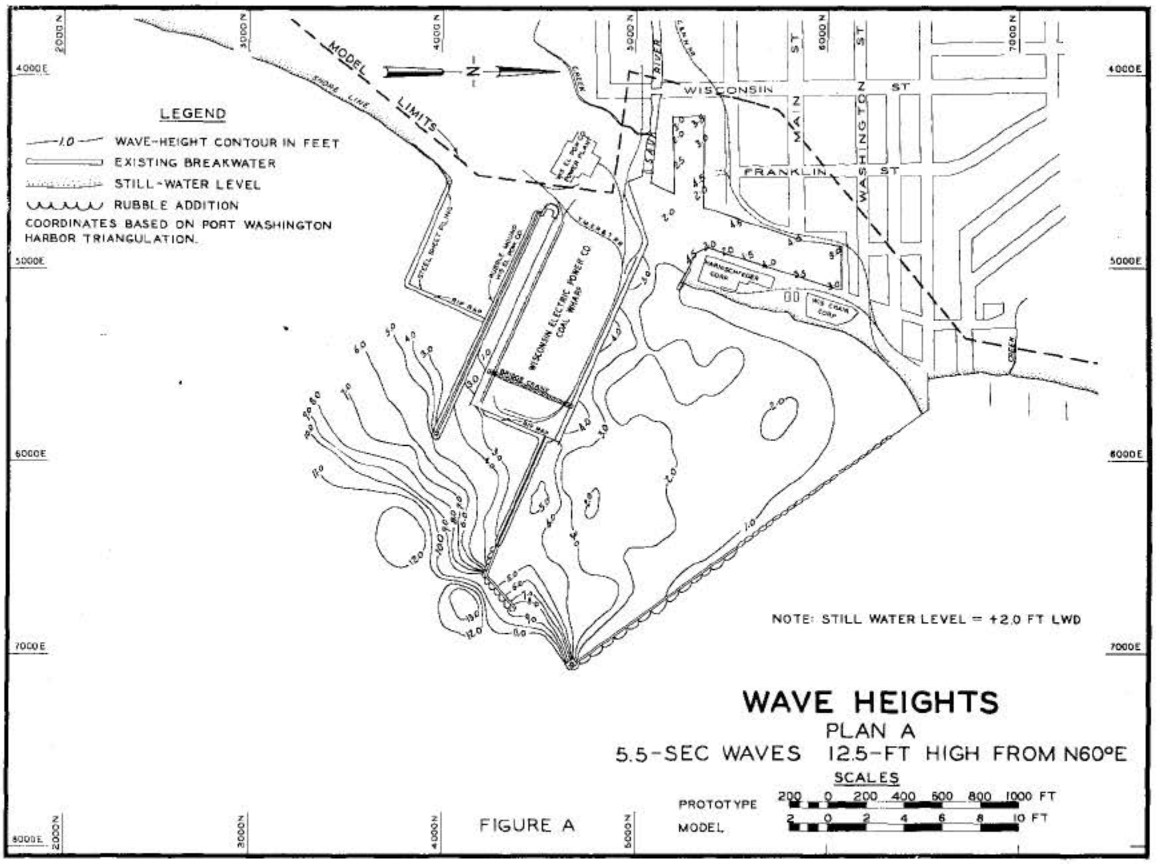


FIGURE A

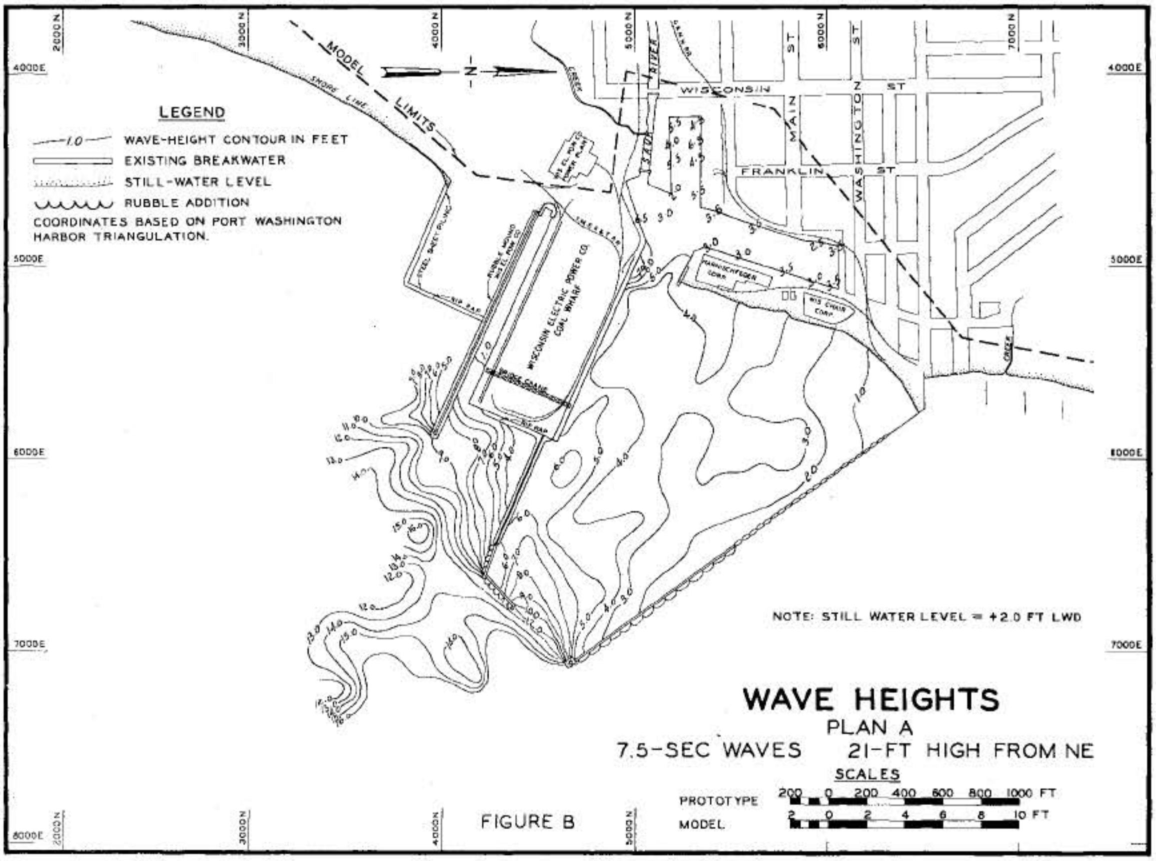


FIGURE B

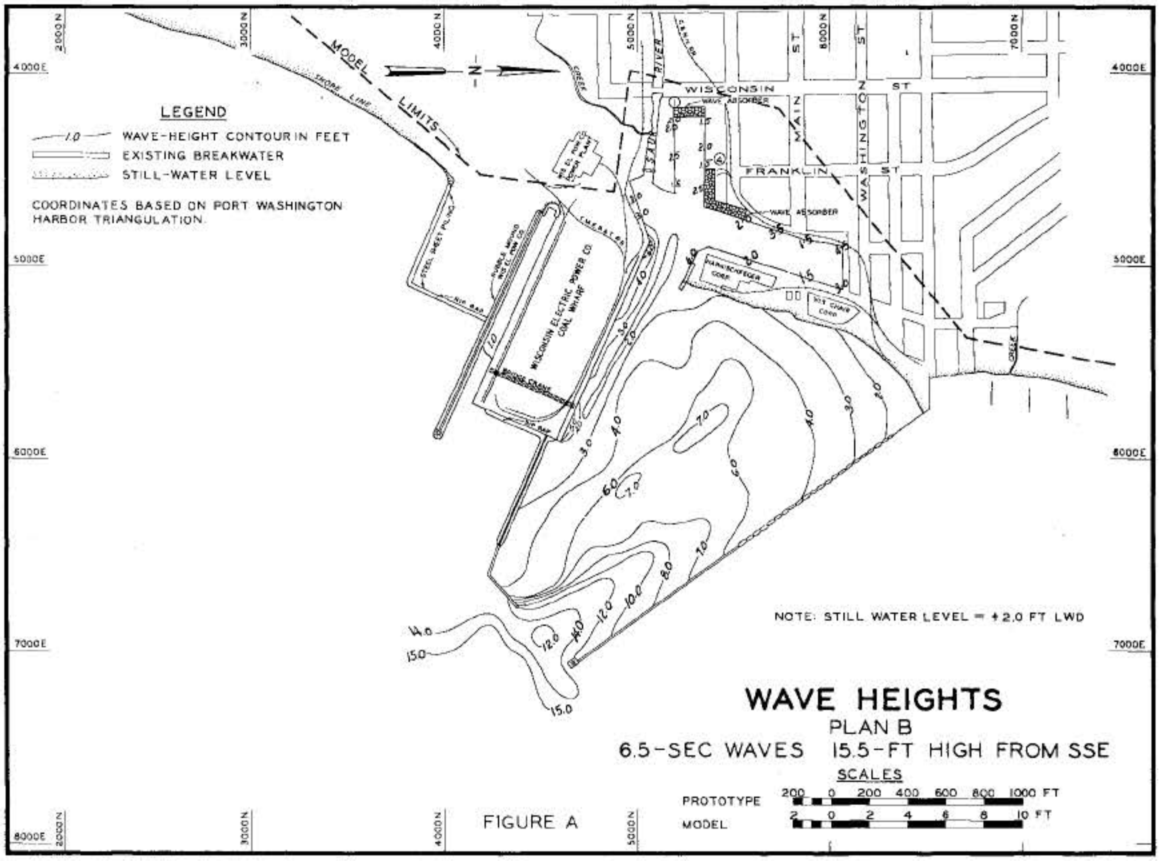


FIGURE A

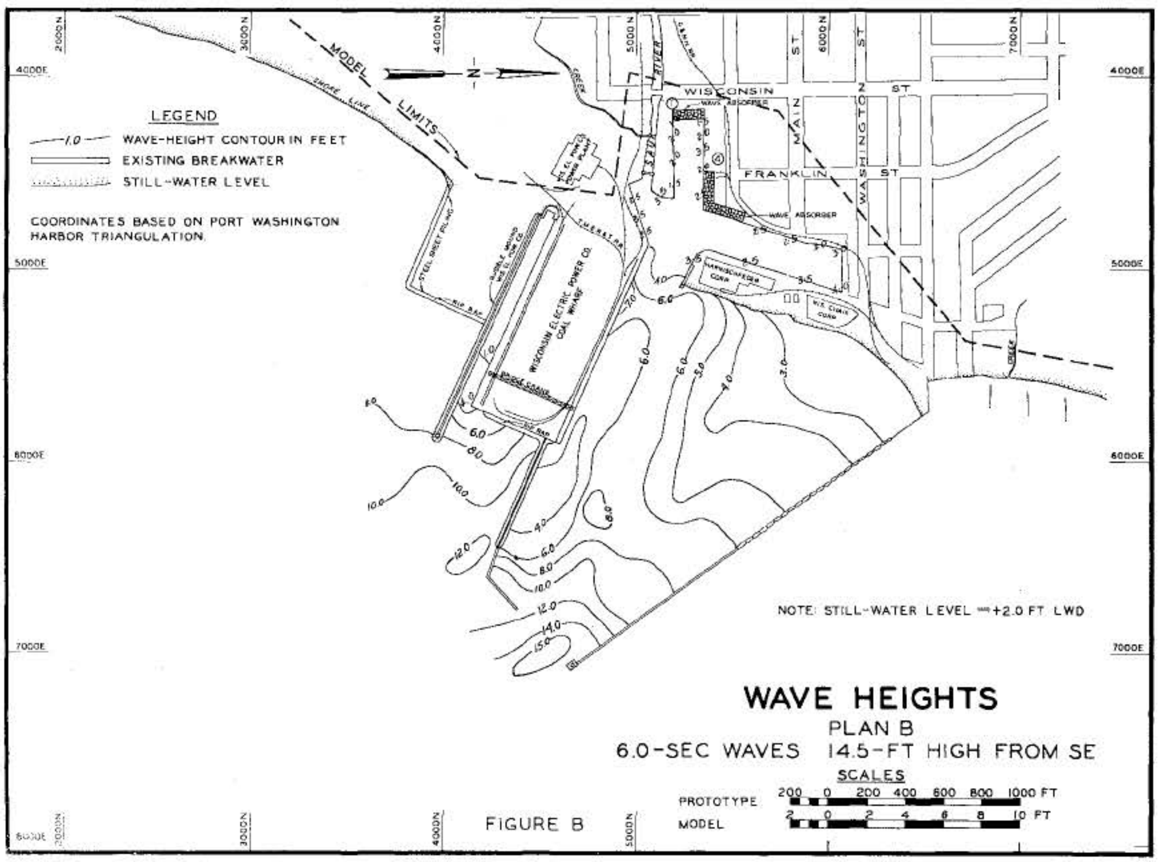


FIGURE B

PLATE 11

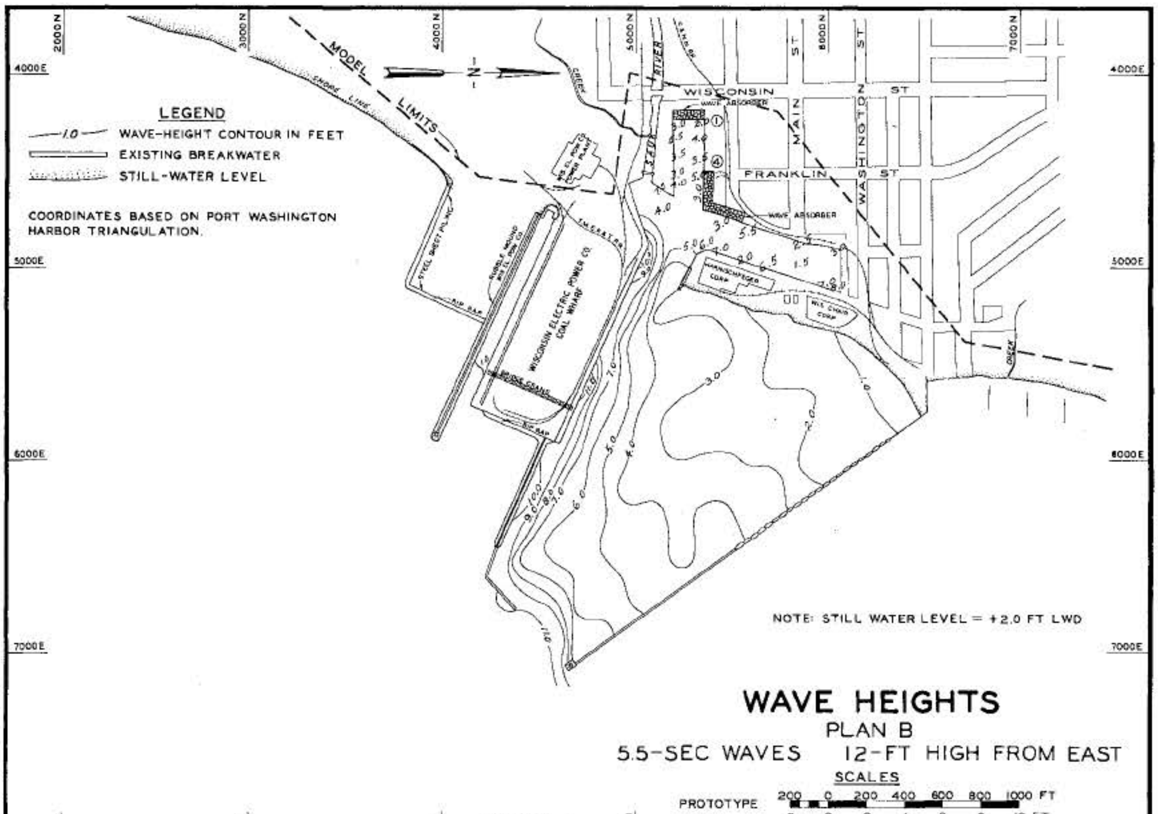


FIGURE A

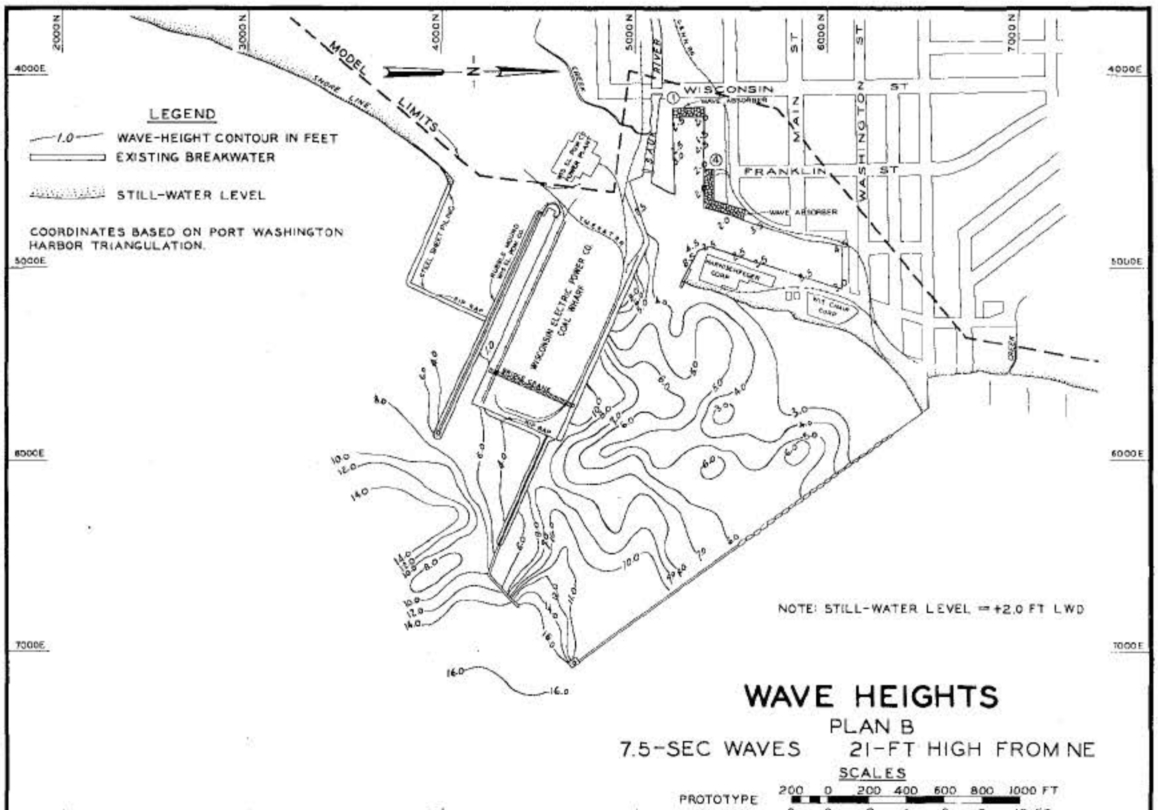


FIGURE B

PLATE 12

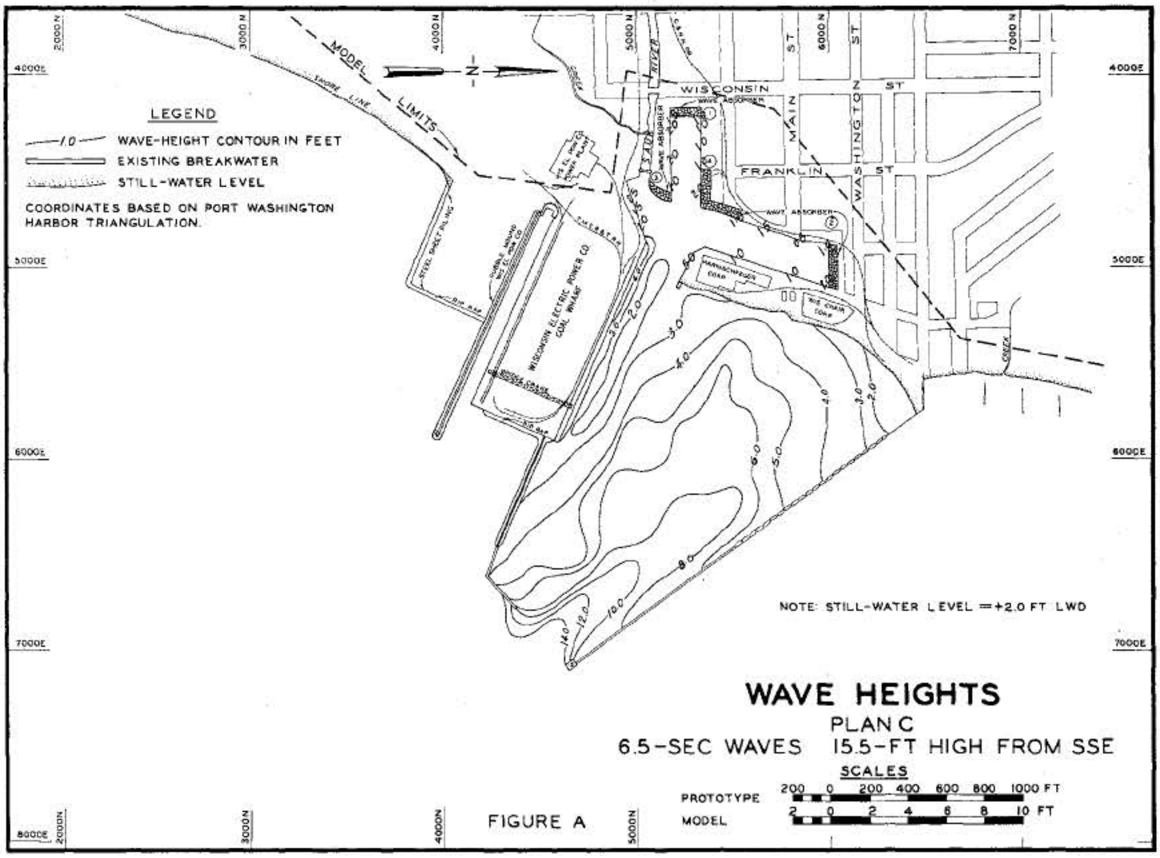


FIGURE A

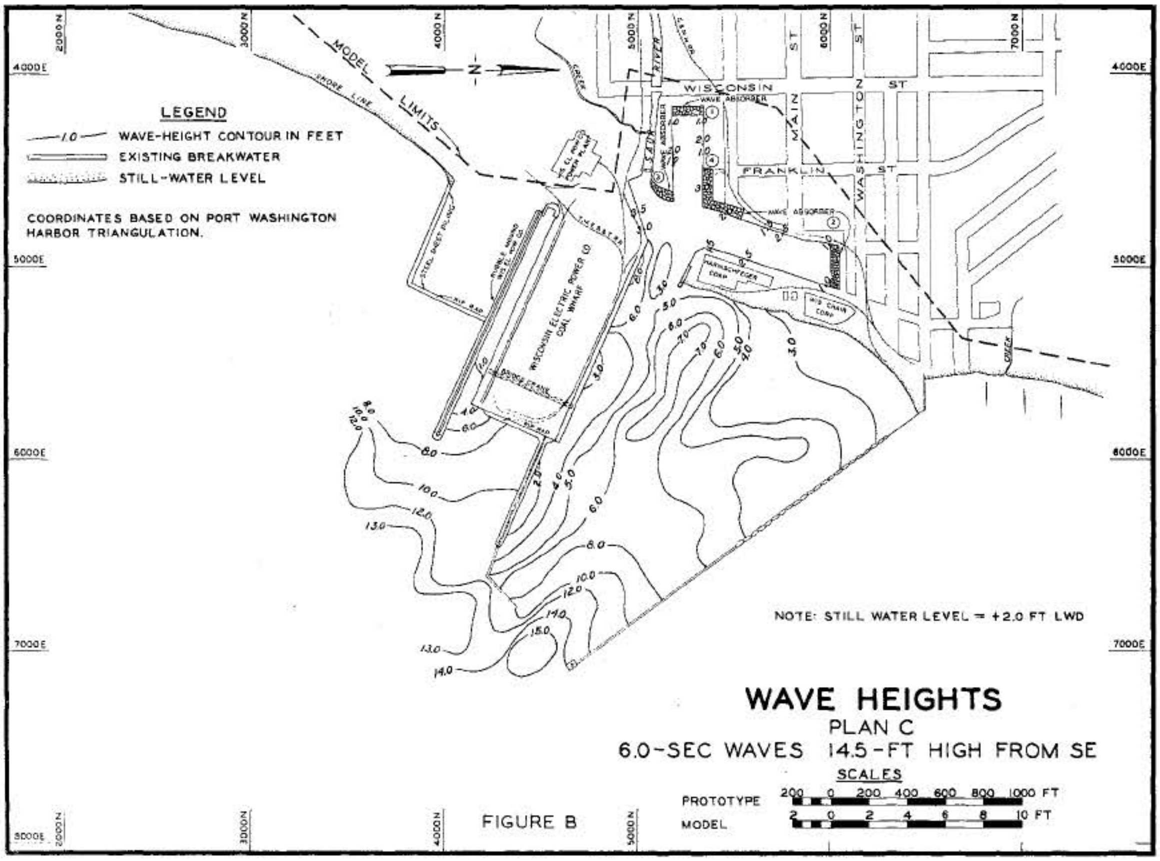


FIGURE B

PLATE 13

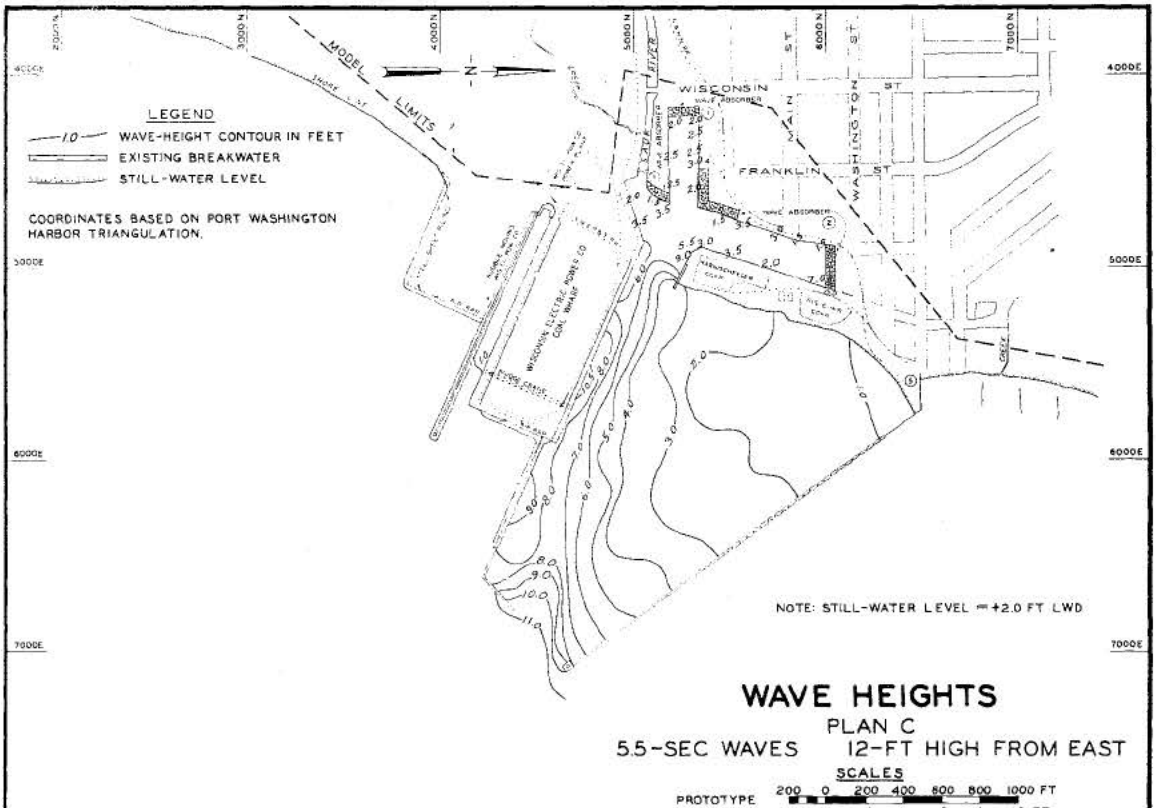


FIGURE A

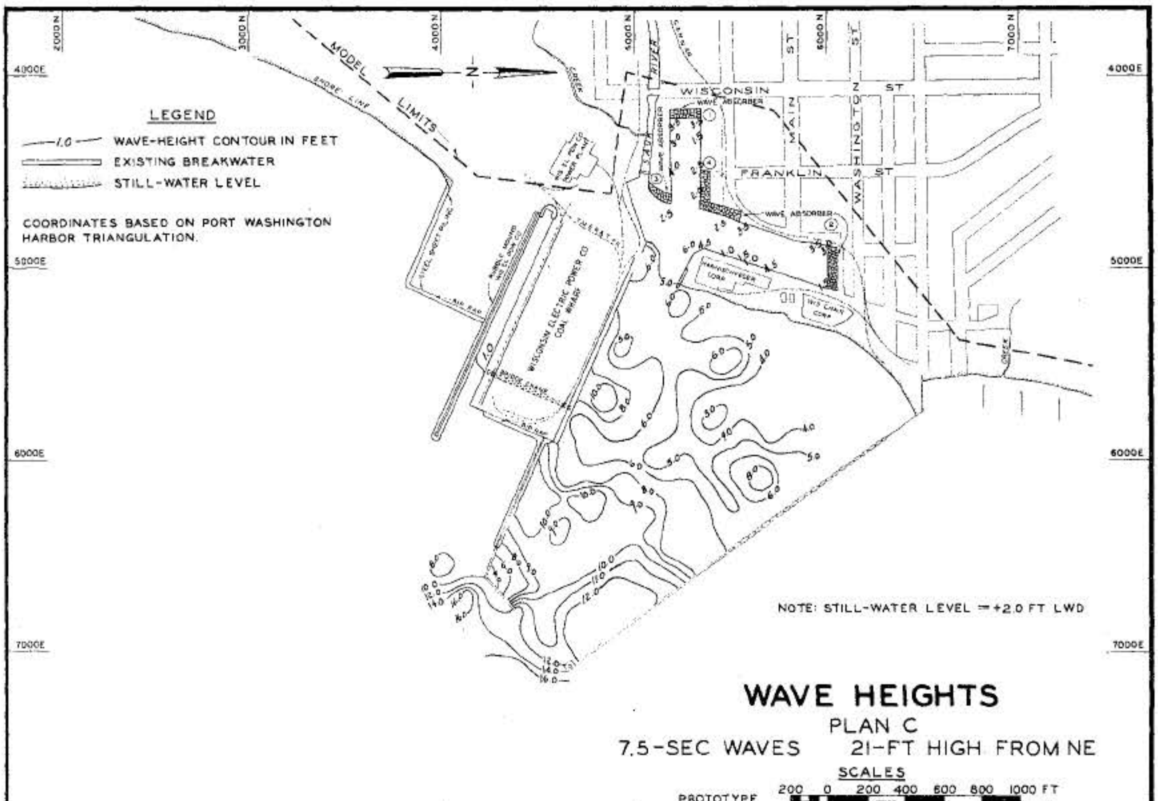


FIGURE B

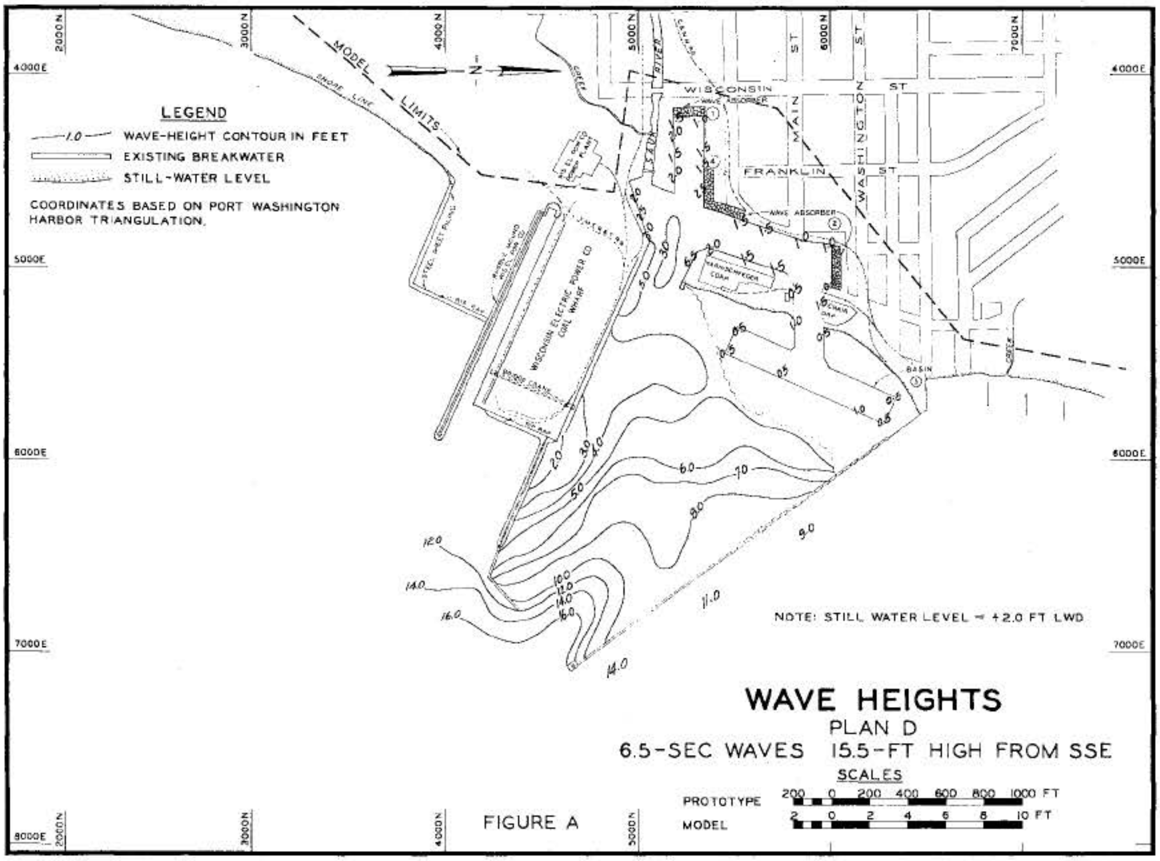


FIGURE A

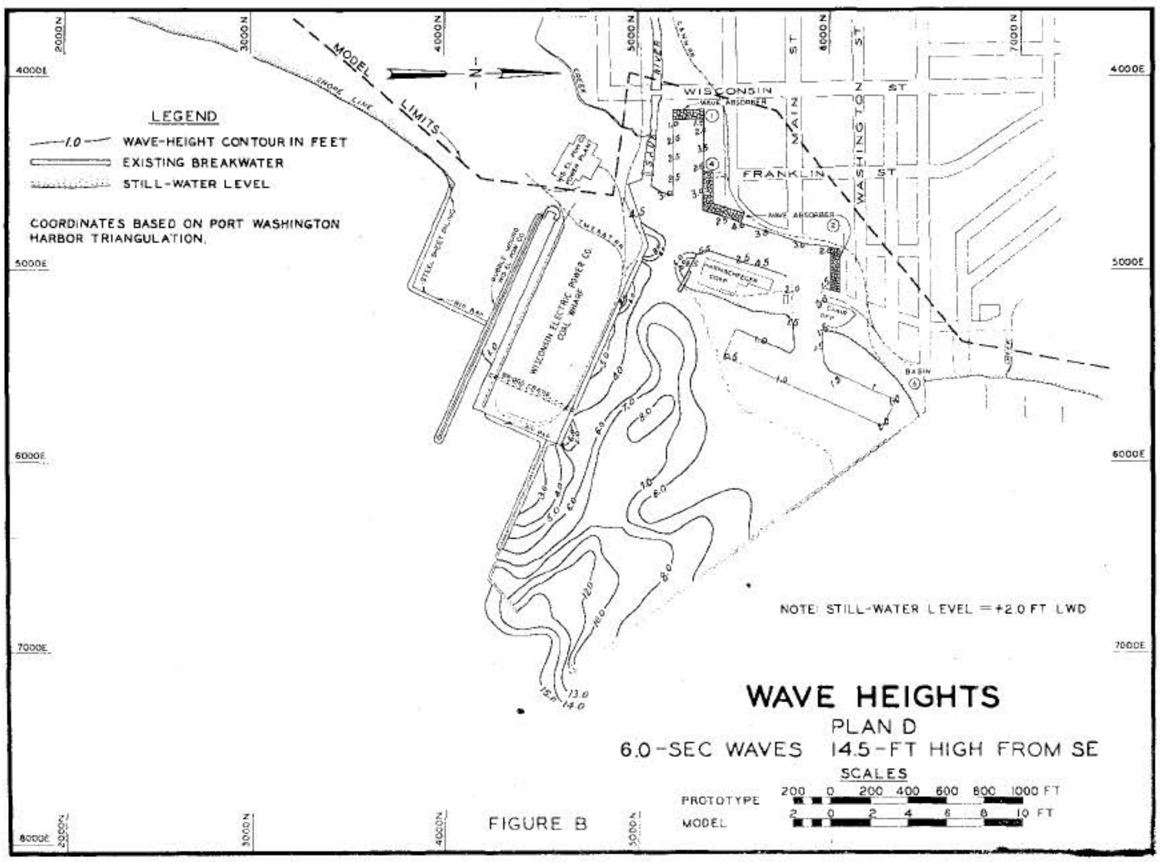


FIGURE B

PLATE 15

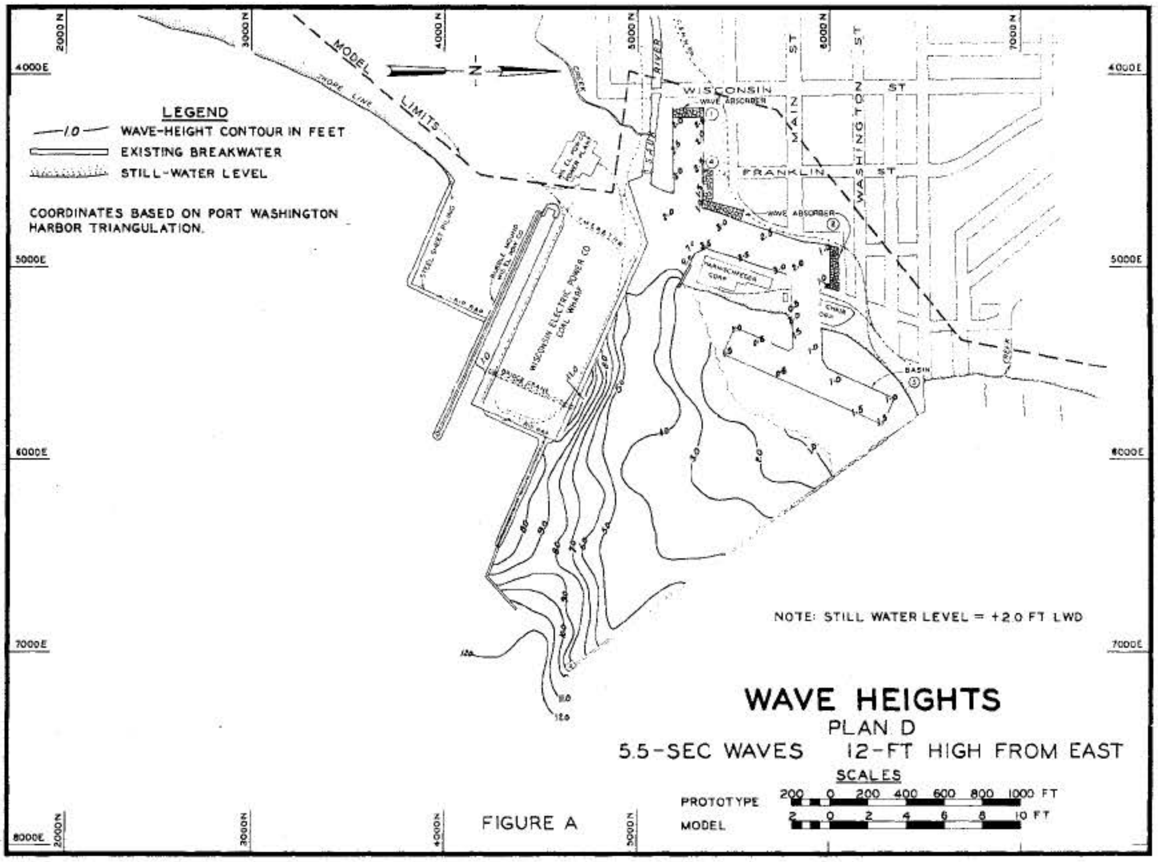


FIGURE A

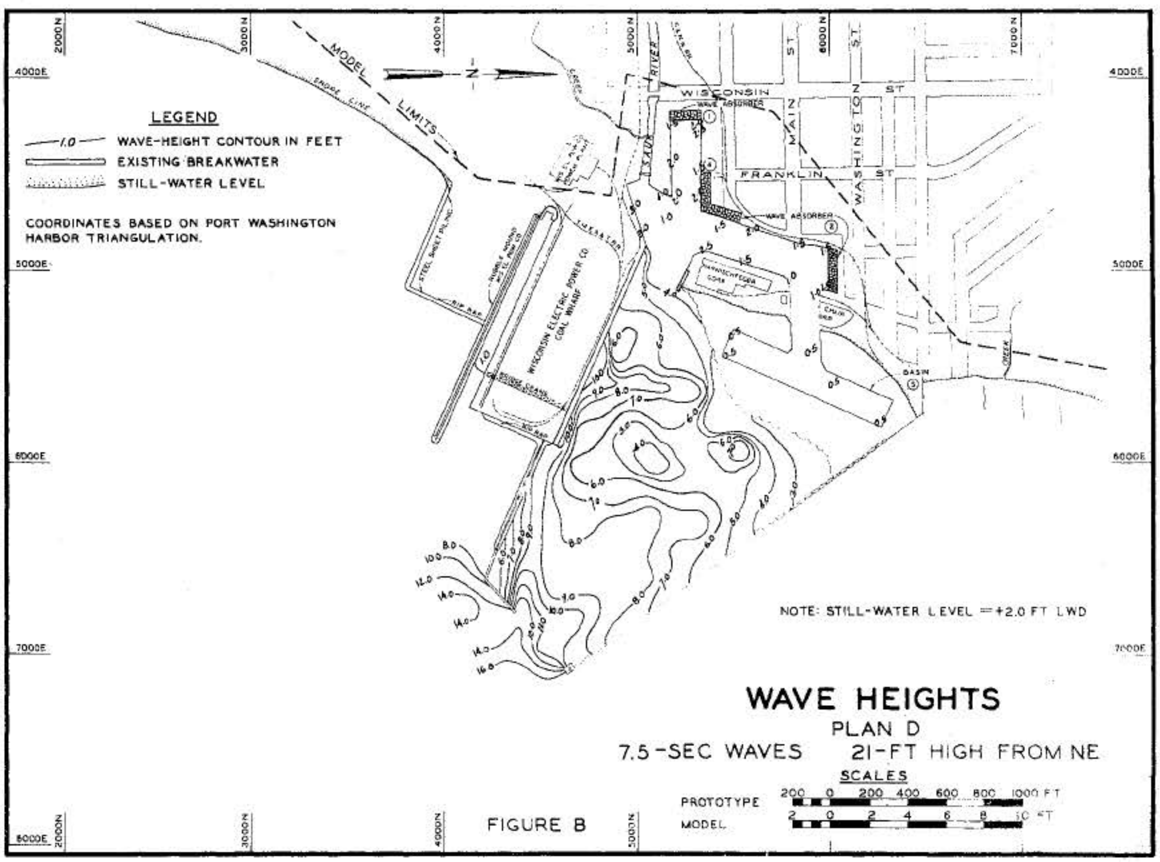


FIGURE B

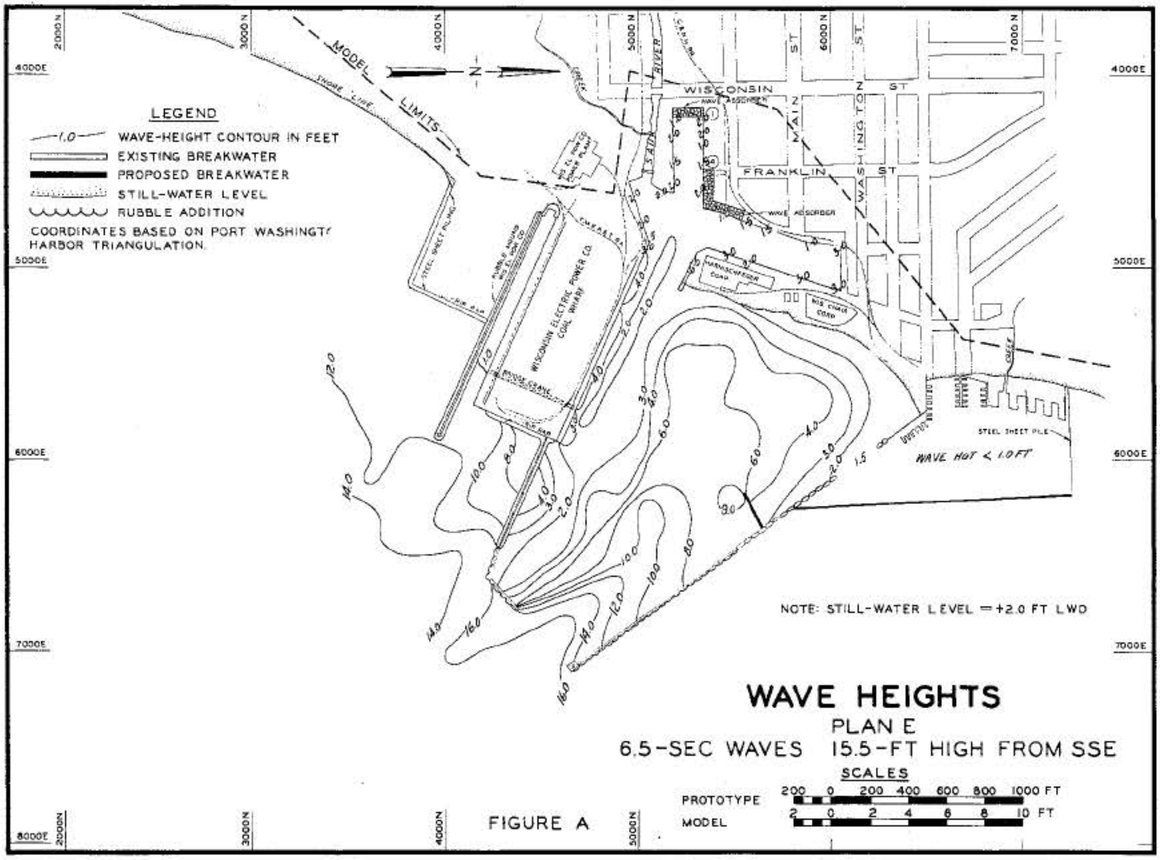


FIGURE A

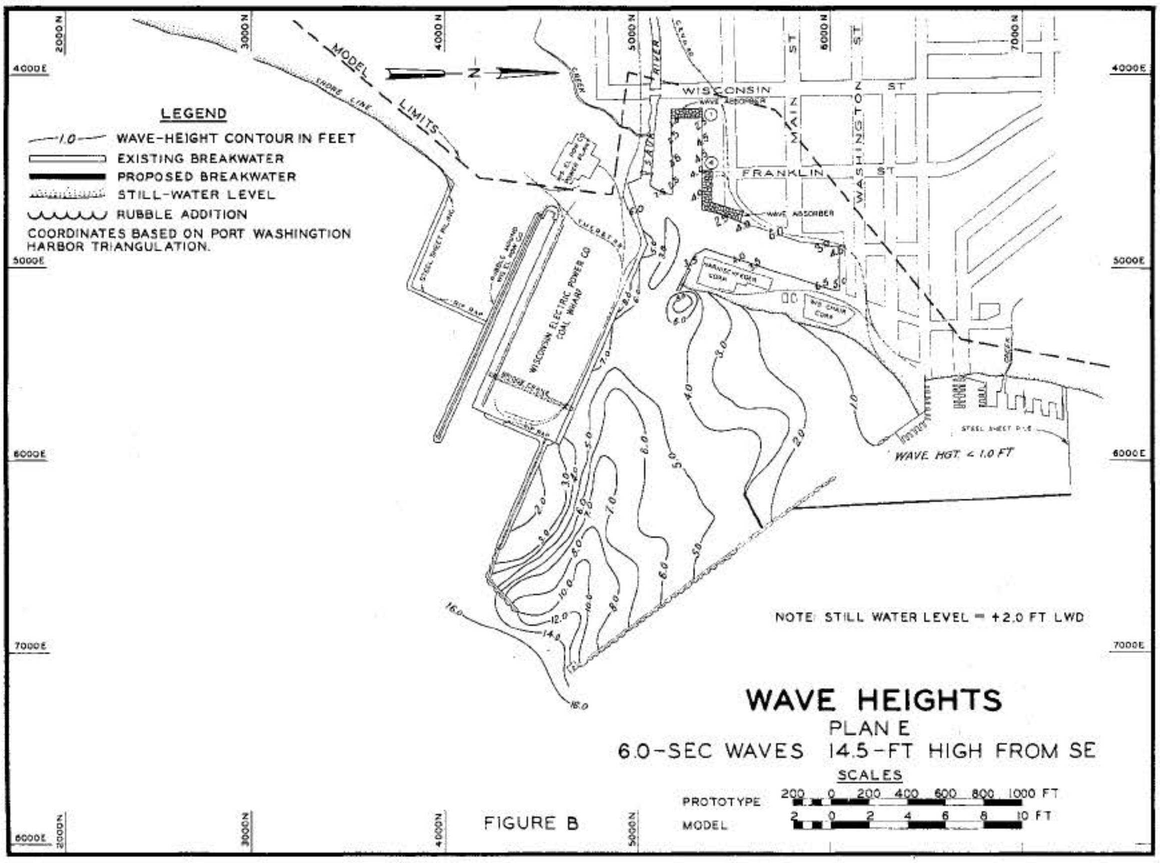


FIGURE B

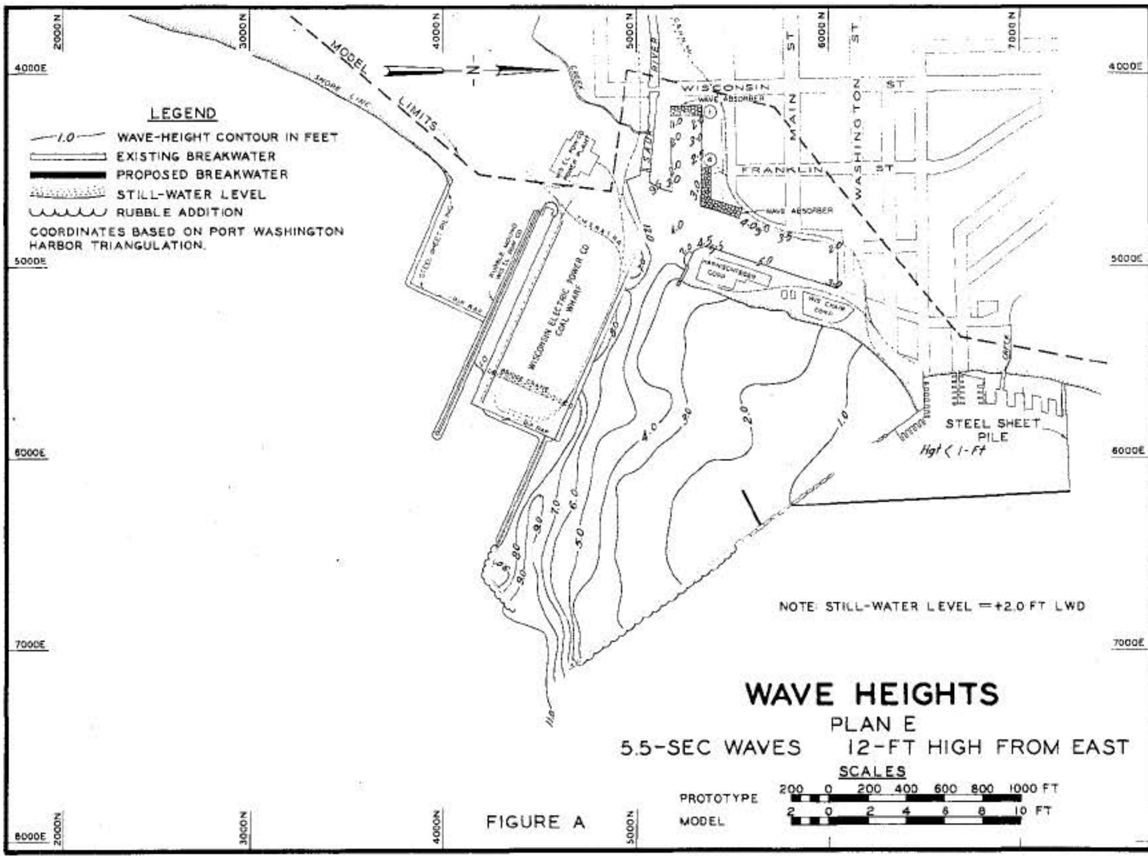


FIGURE A

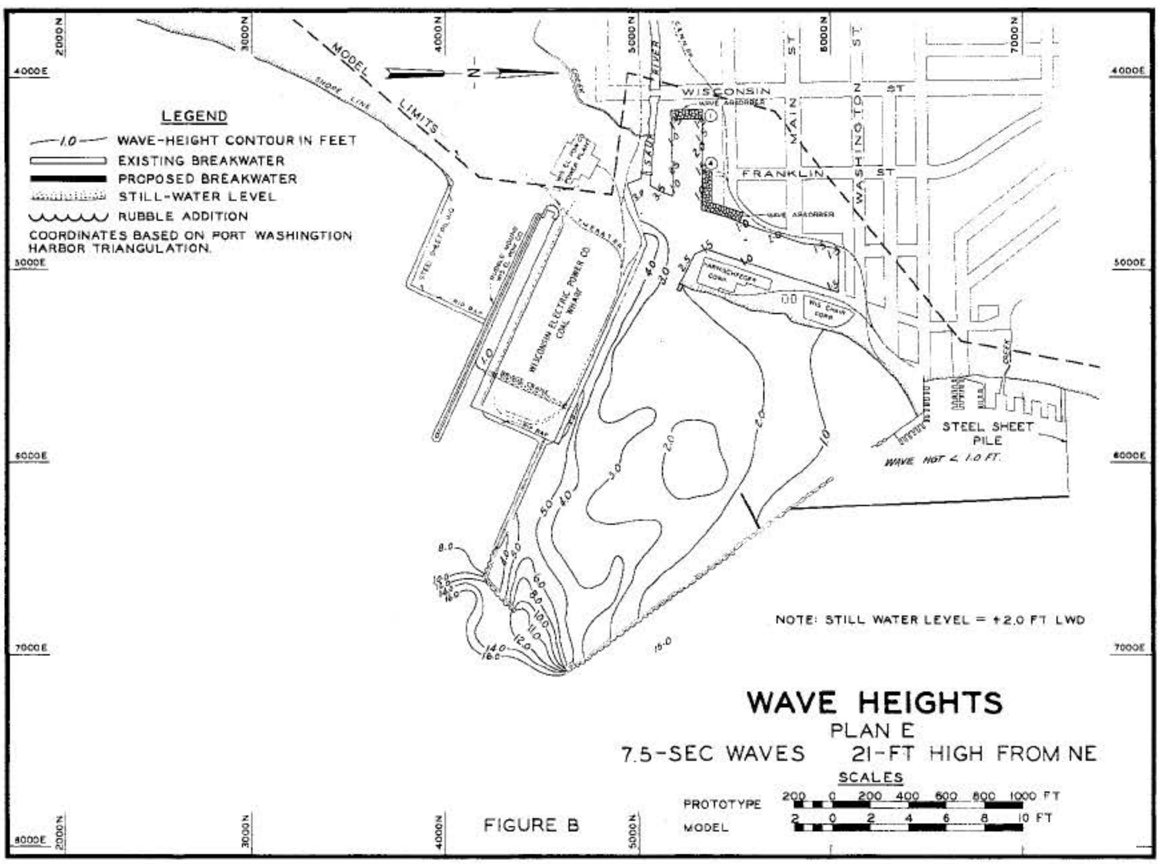


FIGURE B

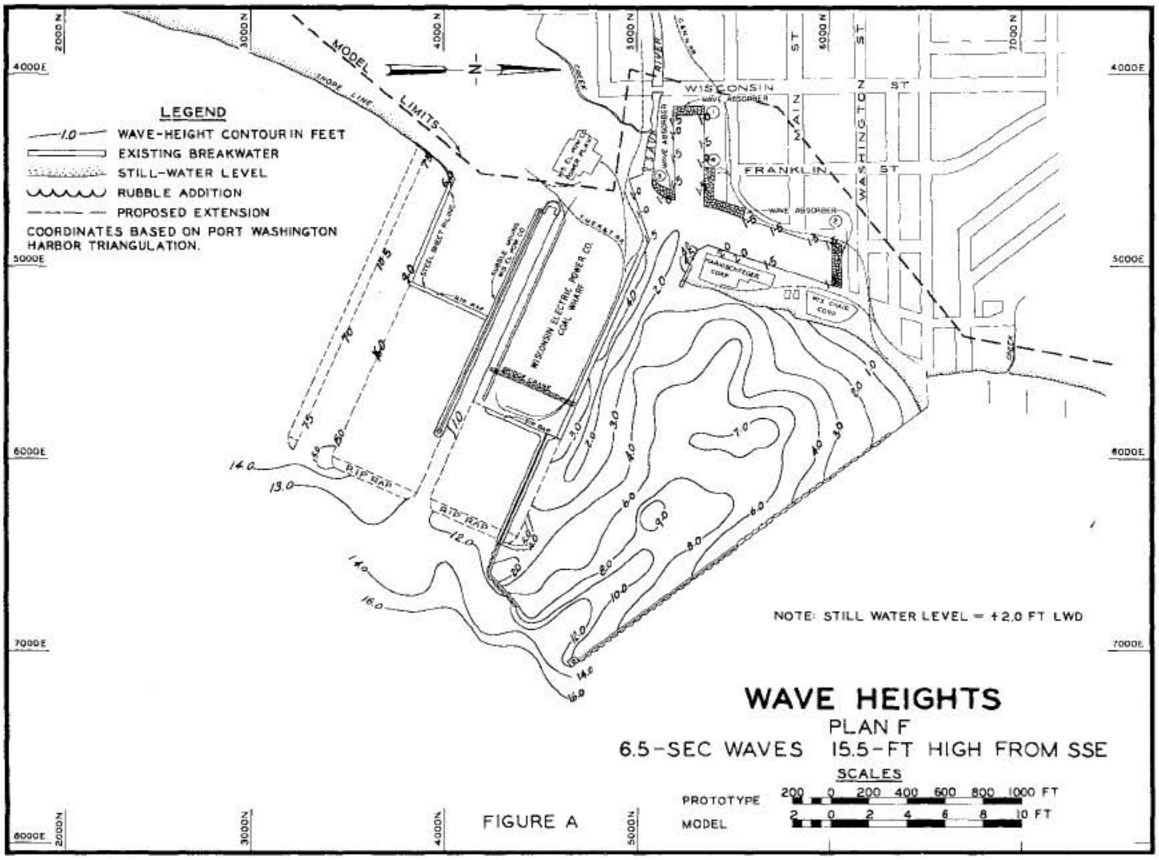


FIGURE A

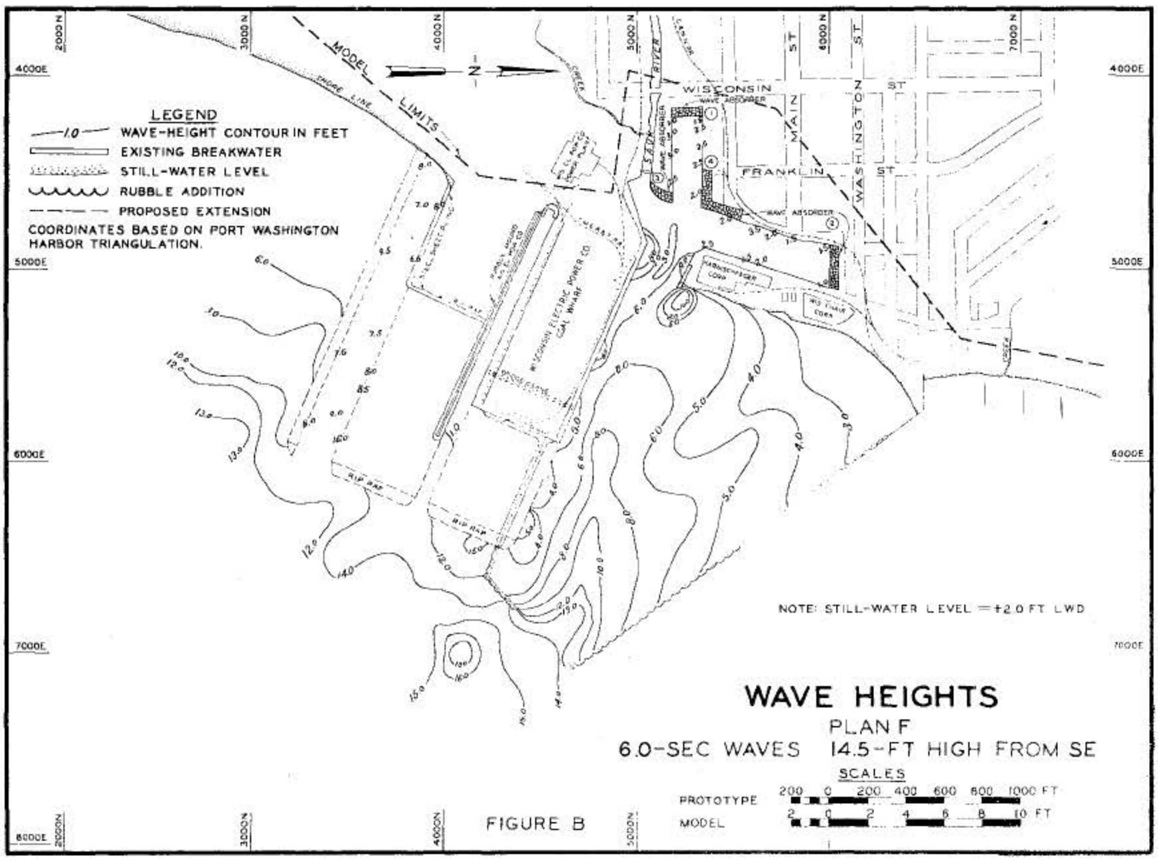
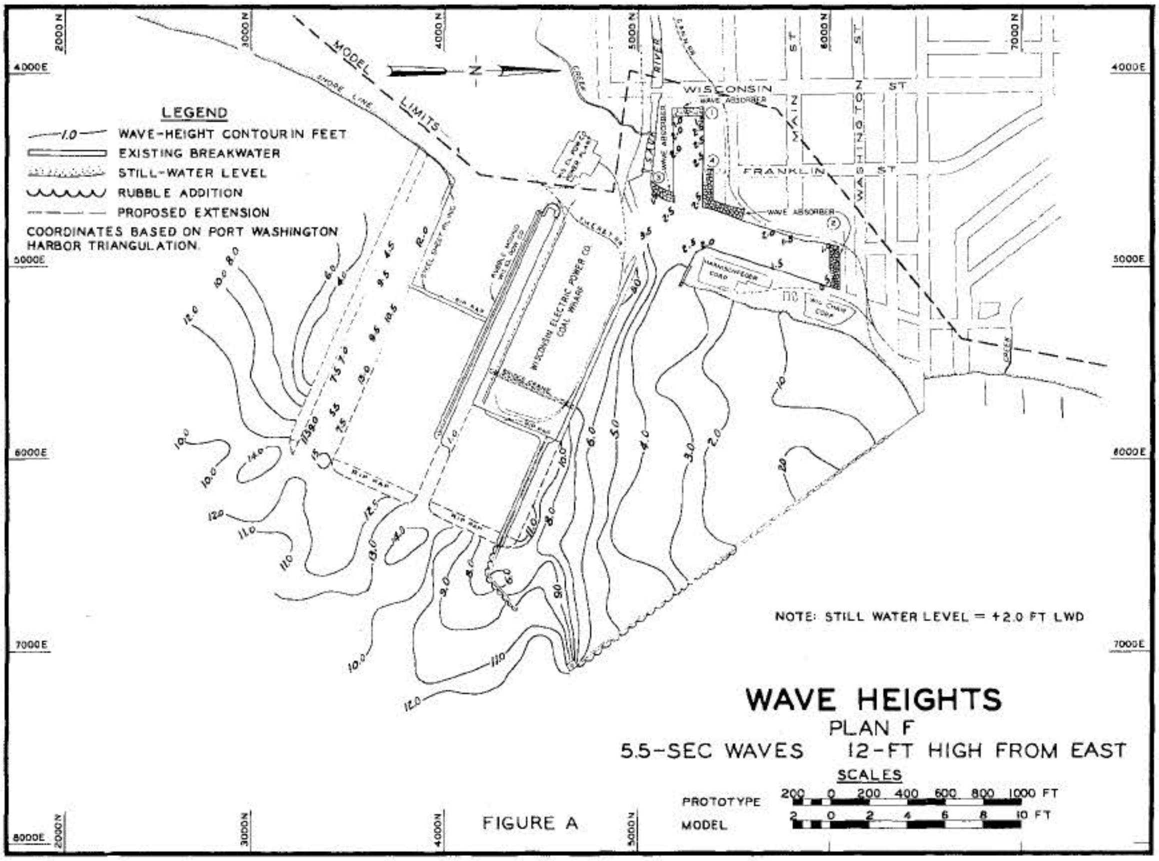


FIGURE B


LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION.
MODEL LIMITS
SHORE LINE
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
WISCONSIN ELECTRIC POWER CO. COAL WHARF
NOTE: STILL WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN F
5.5-SEC WAVES 12-FT HIGH FROM EAST
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE A

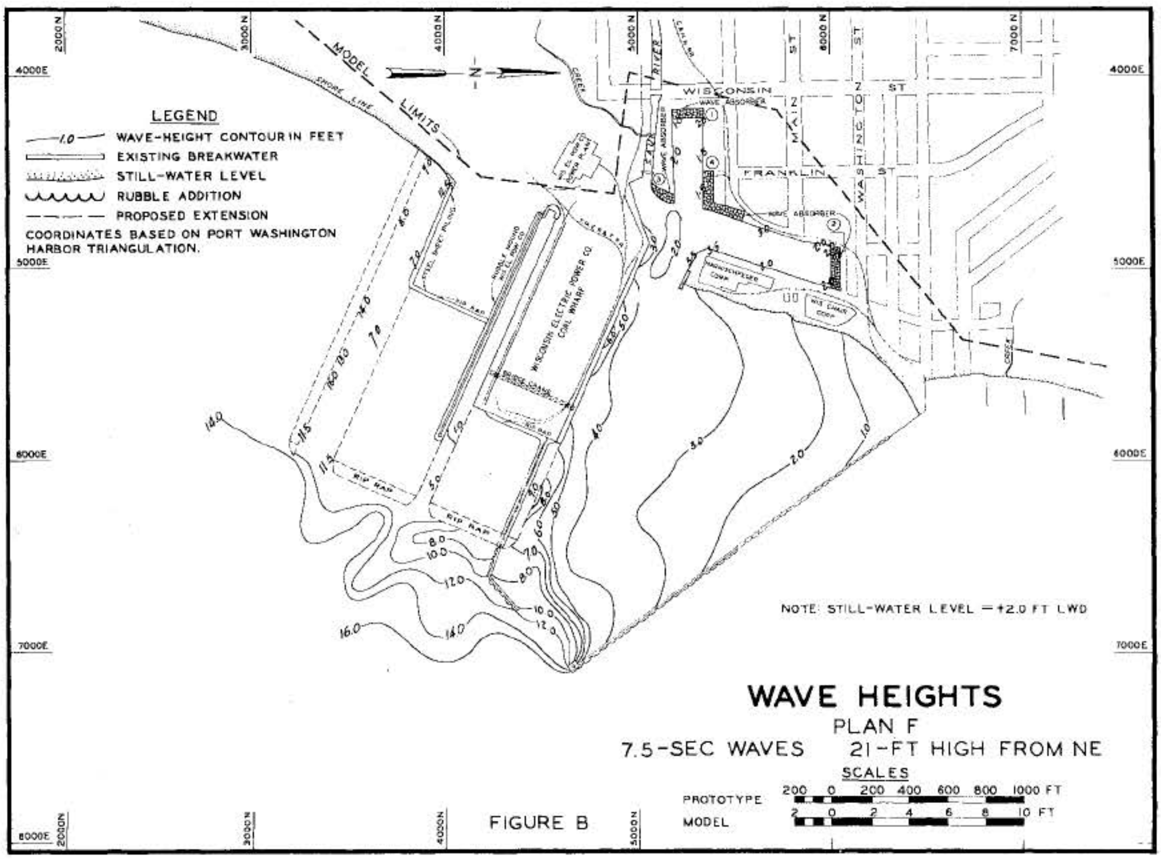

LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION.
MODEL LIMITS
SHORE LINE
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
WISCONSIN ELECTRIC POWER CO. COAL WHARF
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN F
7.5-SEC WAVES 21-FT HIGH FROM NE
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE B

PLATE 20

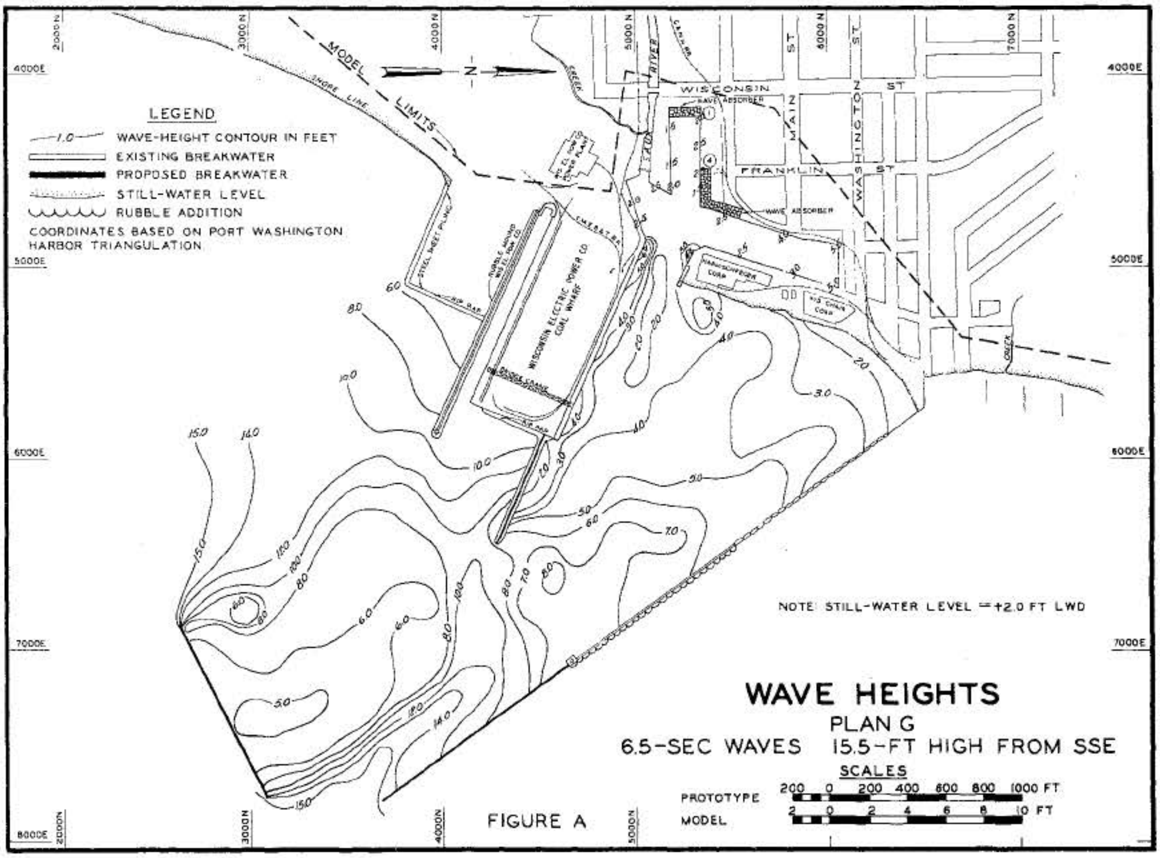


FIGURE A

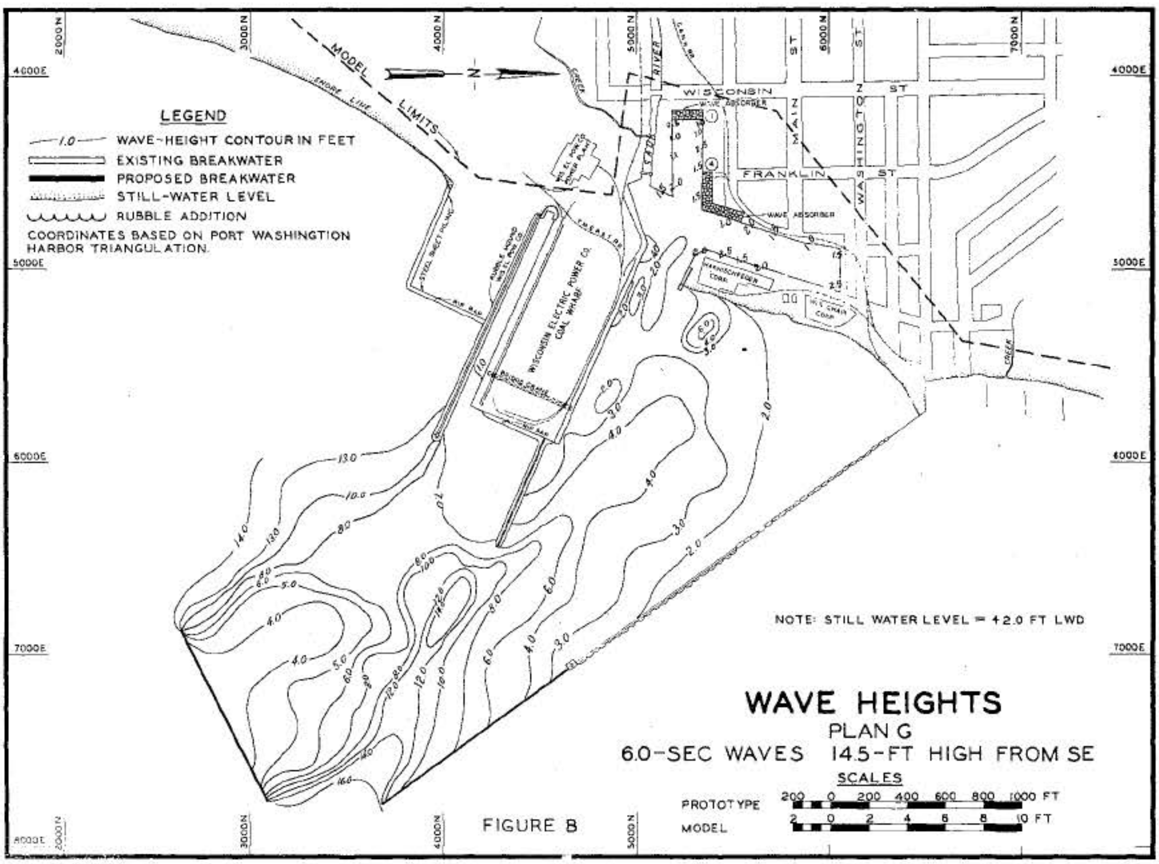
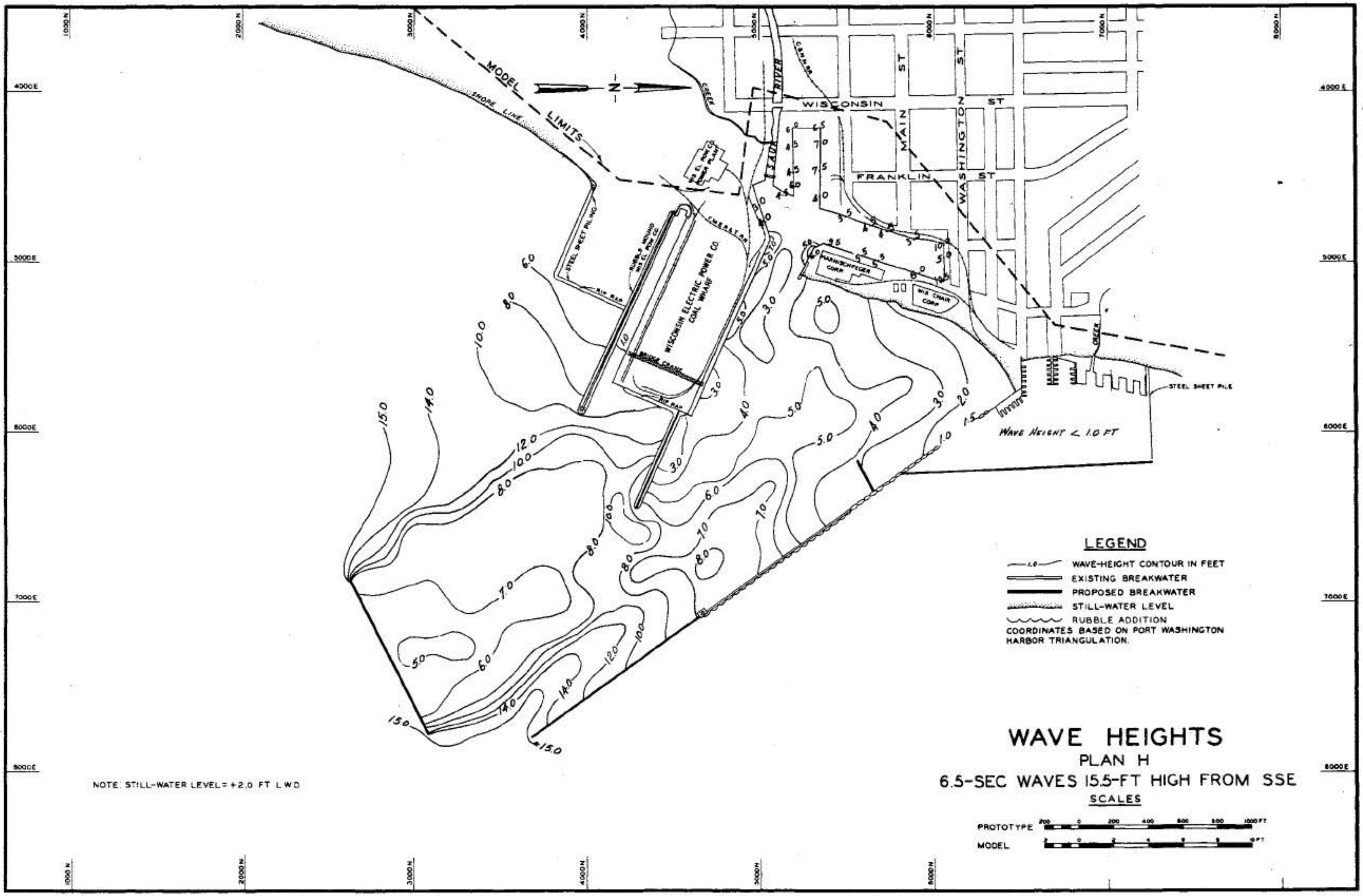


FIGURE B



WAVE HEIGHTS
PLAN H
6.5-SEC WAVES 15.5-FT HIGH FROM SSE

PLATE 22

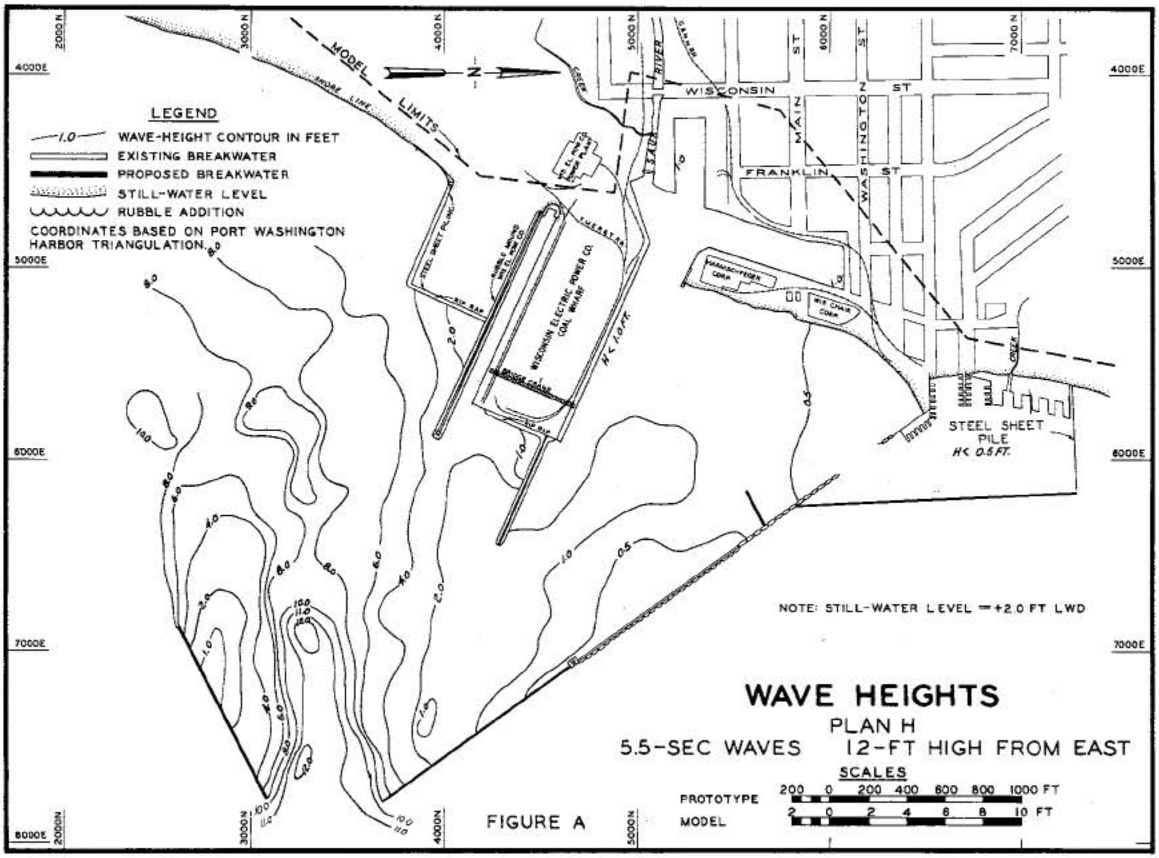


FIGURE A

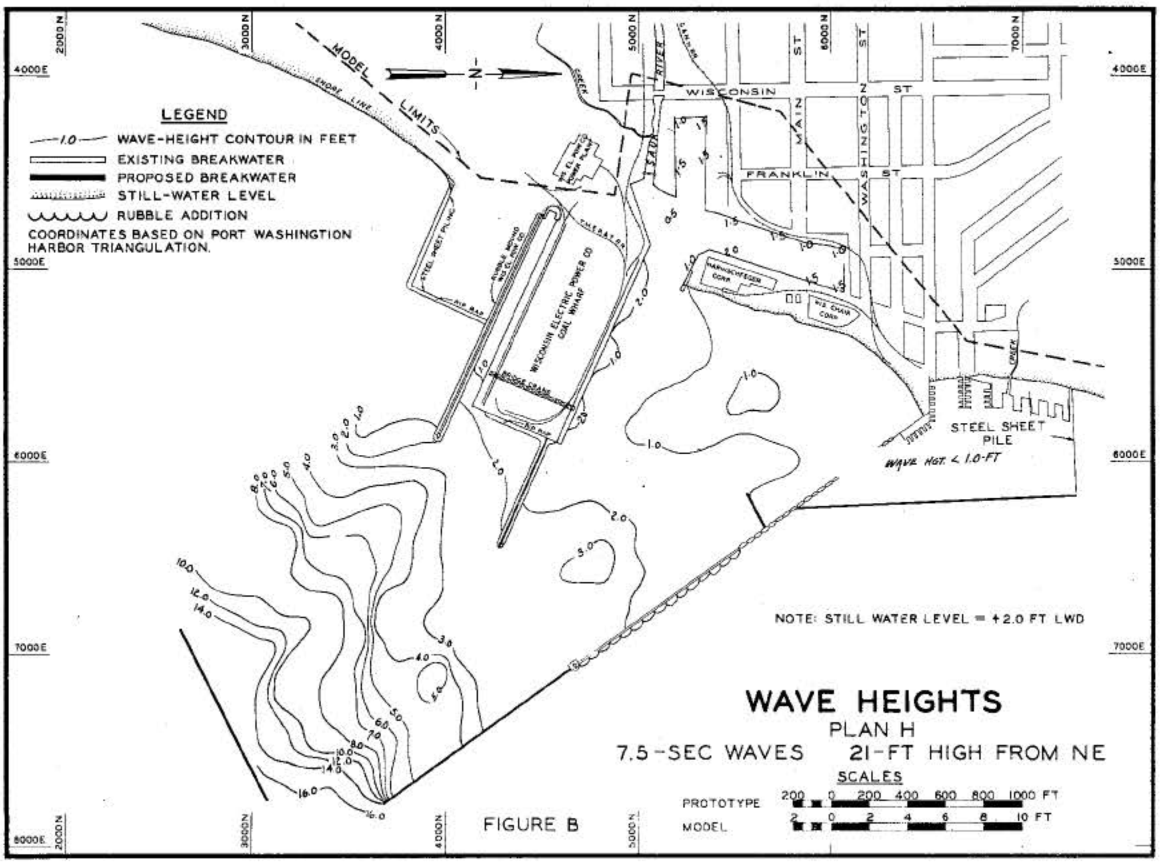


FIGURE B

PLATE 23

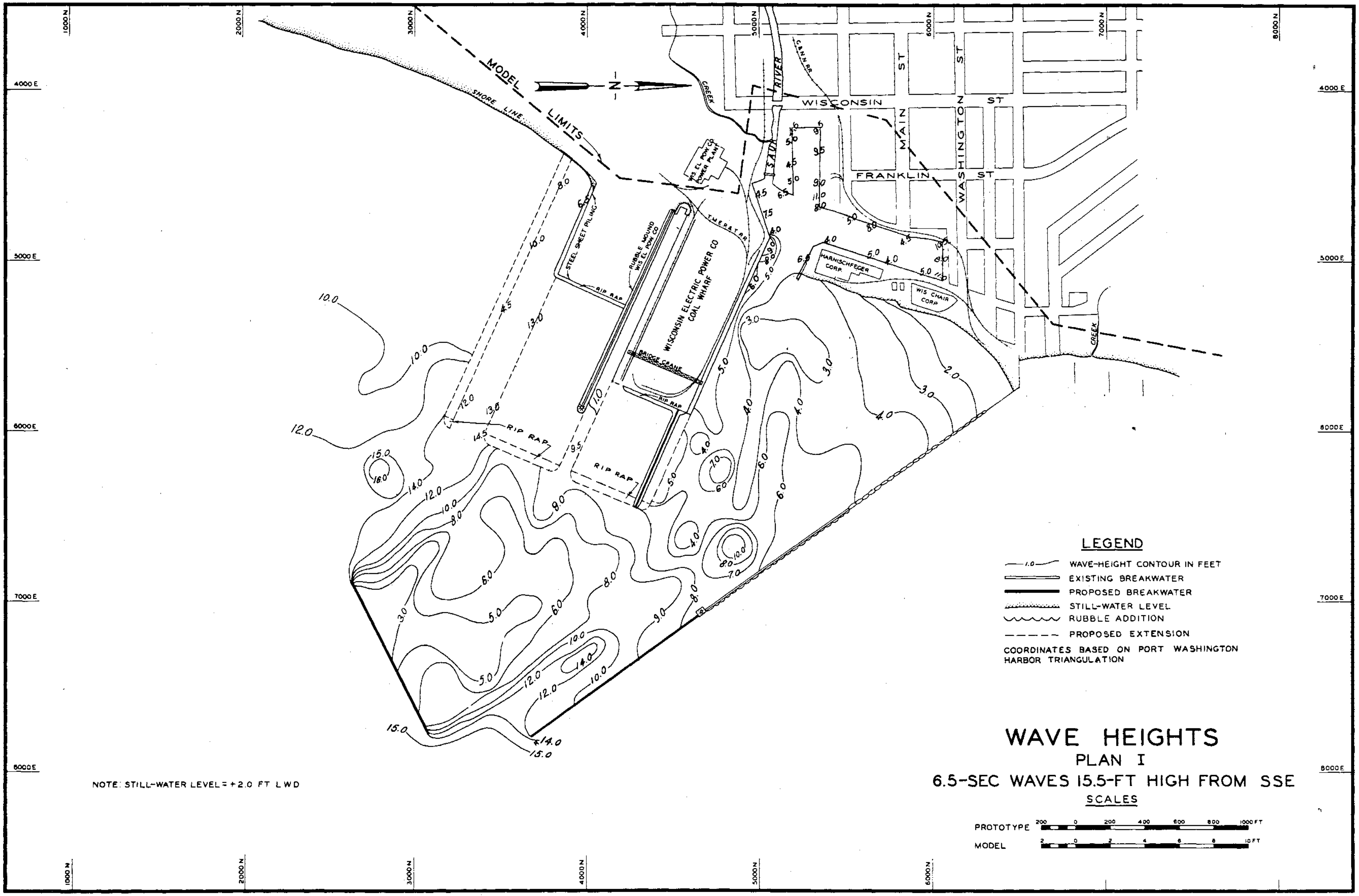
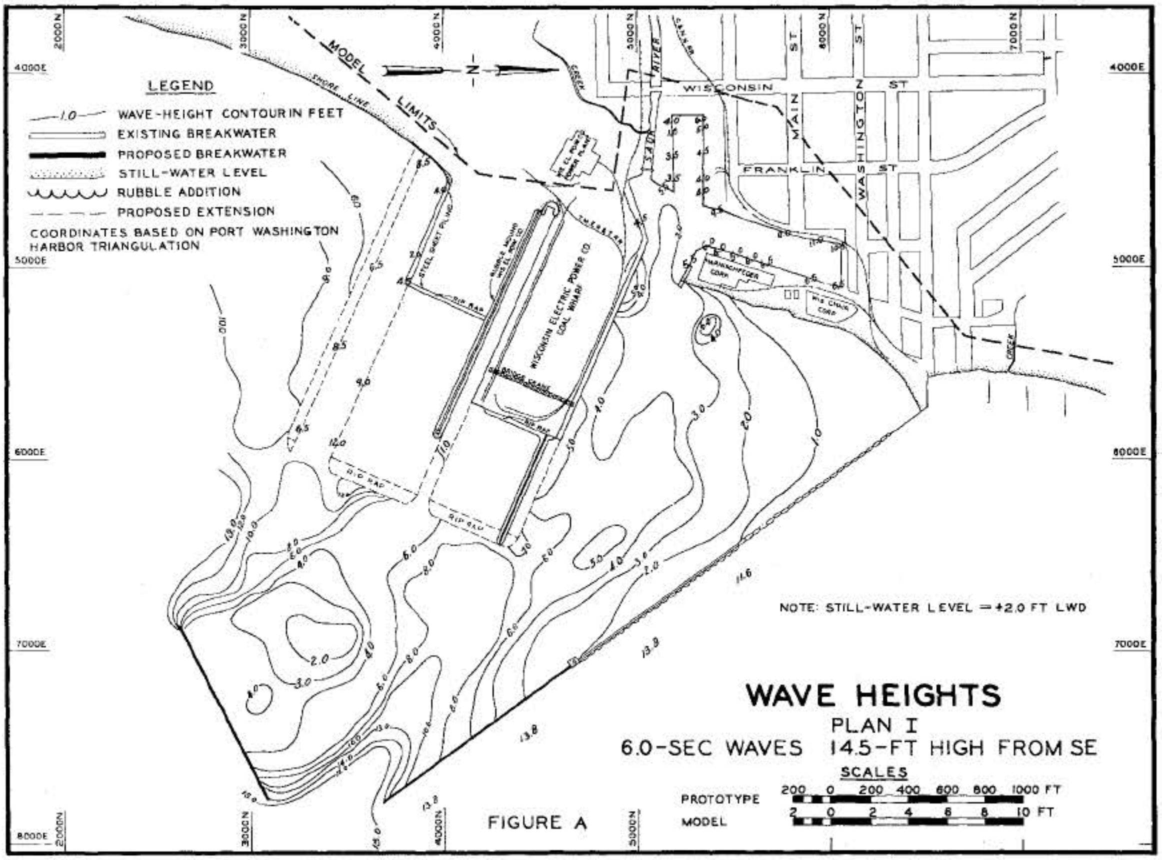

WAVE HEIGHTS
PLAN I
6.5-SEC WAVES 15.5-FT HIGH FROM SSE
SCALES
PROTOTYPE
MODEL
LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
MODEL LIMITS
SHORE LINE
WISCONSIN ELECTRIC POWER CO COAL WHARF
RUBBLE MOUND WIS EL POW CO
STEEL SHEET PILING
RIP RAP
BRIDGE CRANE
HARNISCHFEGER CORP.
WIS CHAIR CORP
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
CREEK

PLATE 24


LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION
MODEL LIMITS
SHORE LINE
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
WISCONSIN ELECTRIC POWER CO. COAL WHARF
STEEL SHEET PILING
RIP RAP
BRIDGE CRANE
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN I
6.0-SEC WAVES 14.5-FT HIGH FROM SE
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE A

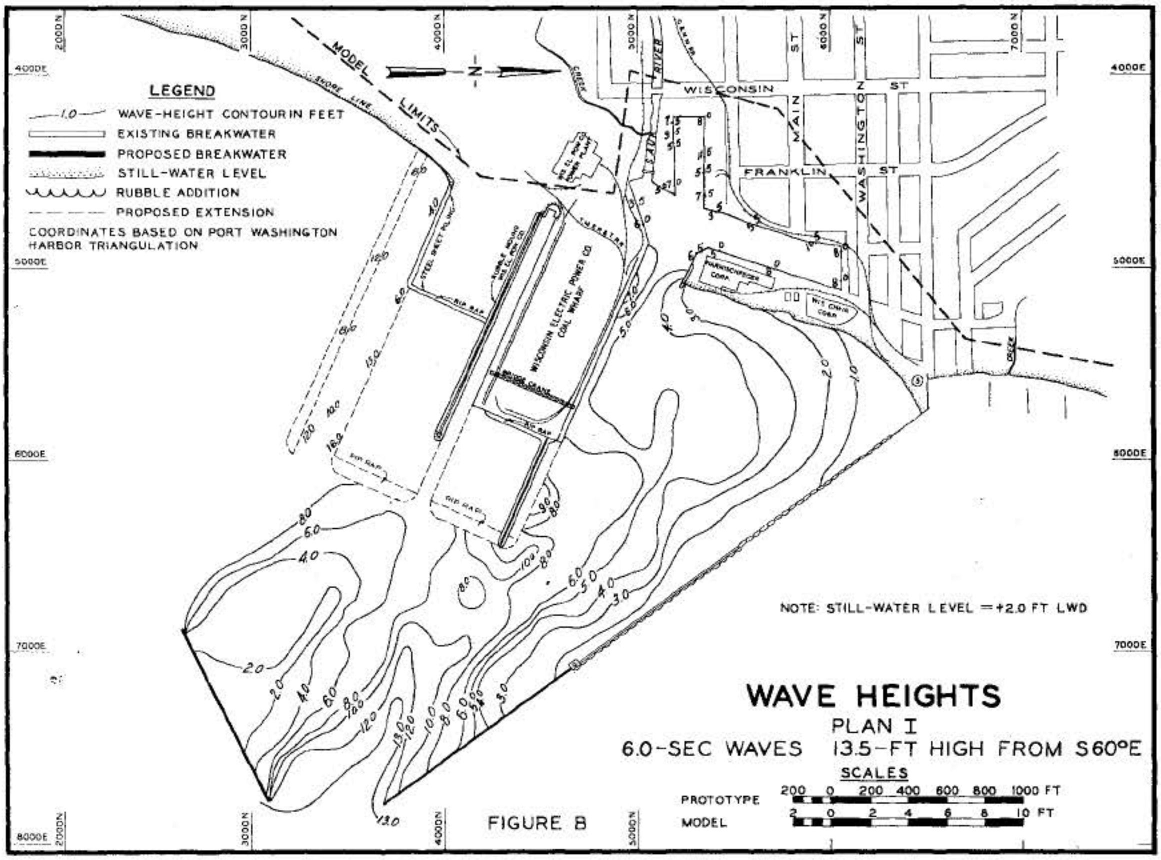

LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION
MODEL LIMITS
SHORE LINE
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
WISCONSIN ELECTRIC POWER CO. COAL WHARF
STEEL SHEET PILING
RIP RAP
BRIDGE CRANE
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN I
6.0-SEC WAVES 13.5-FT HIGH FROM S60°E
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE B

PLATE 25

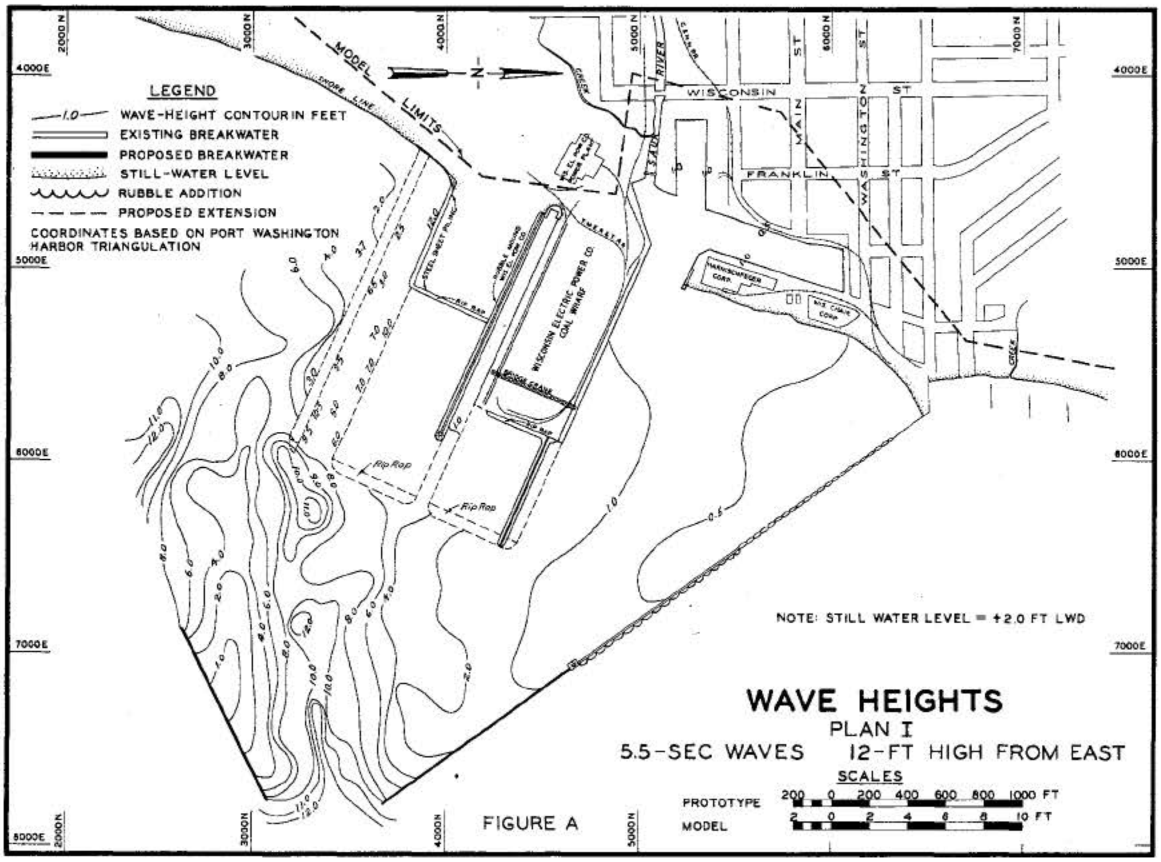


FIGURE A

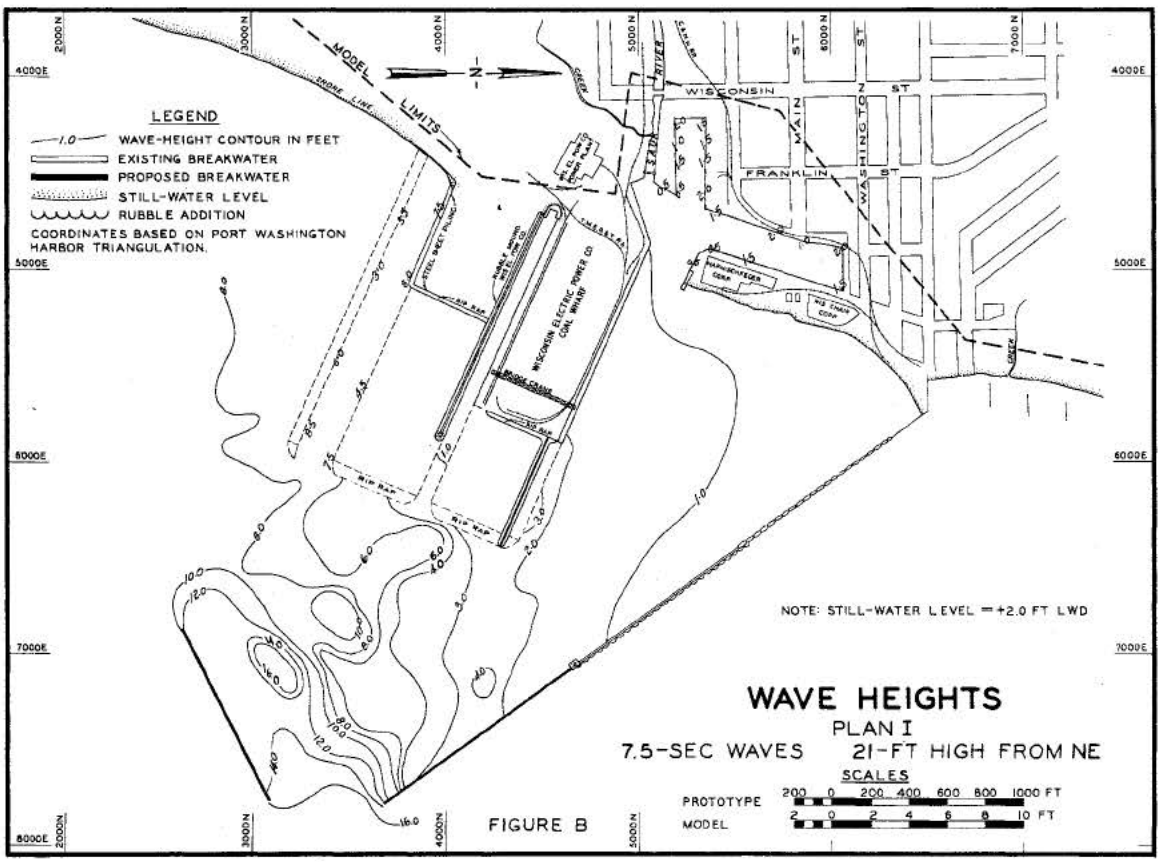


FIGURE B

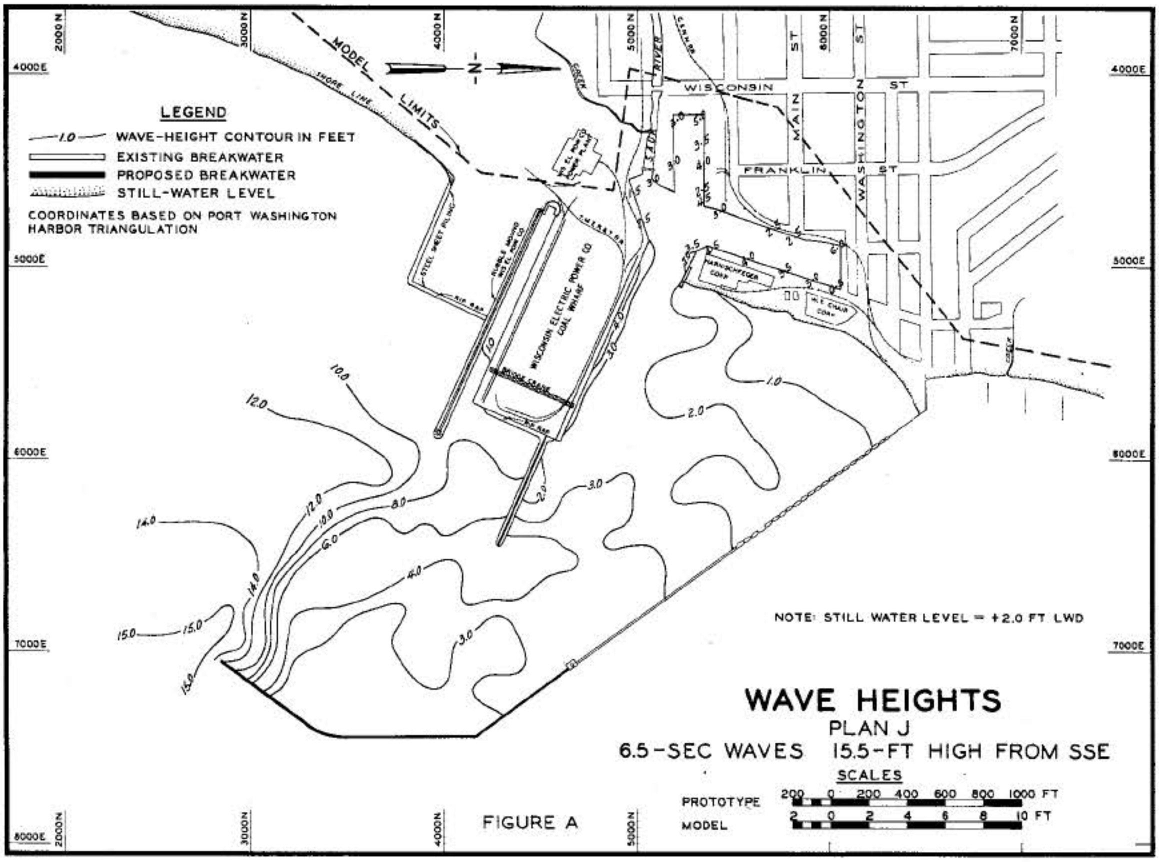


FIGURE A

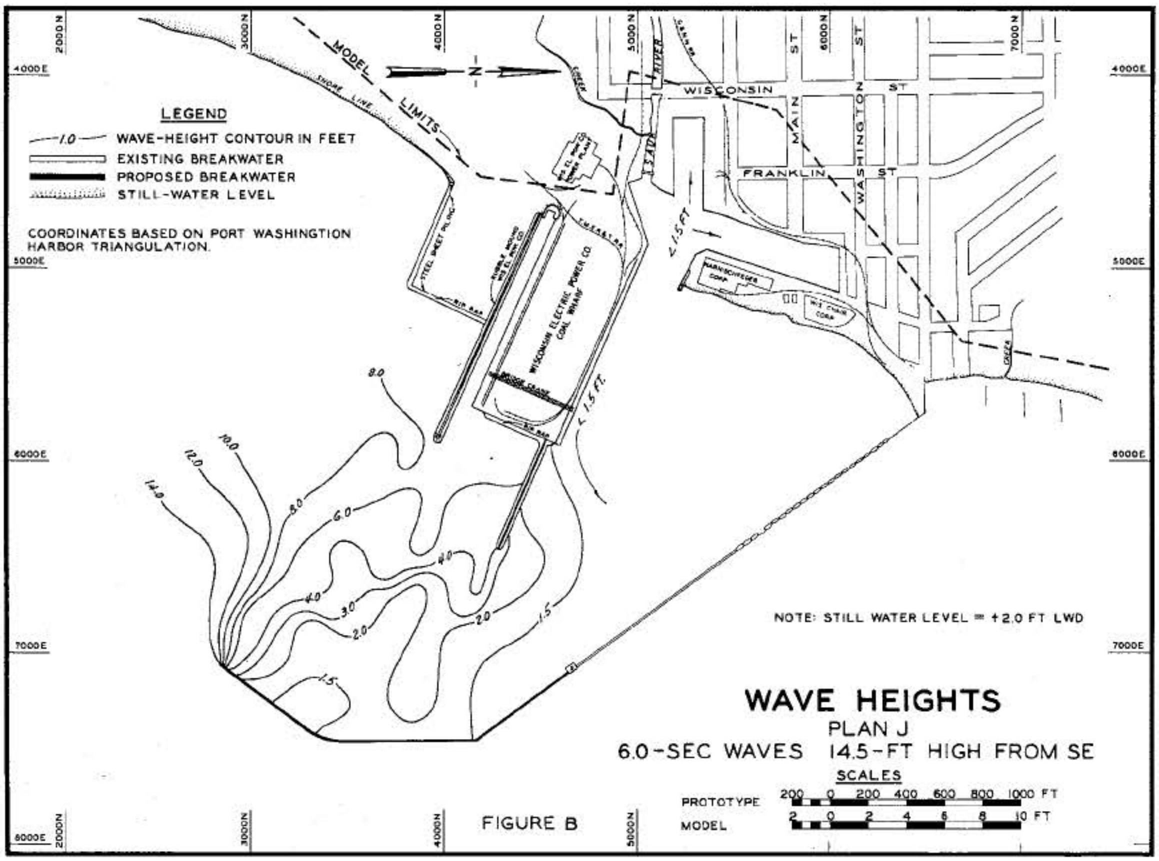


FIGURE B

PLATE 27

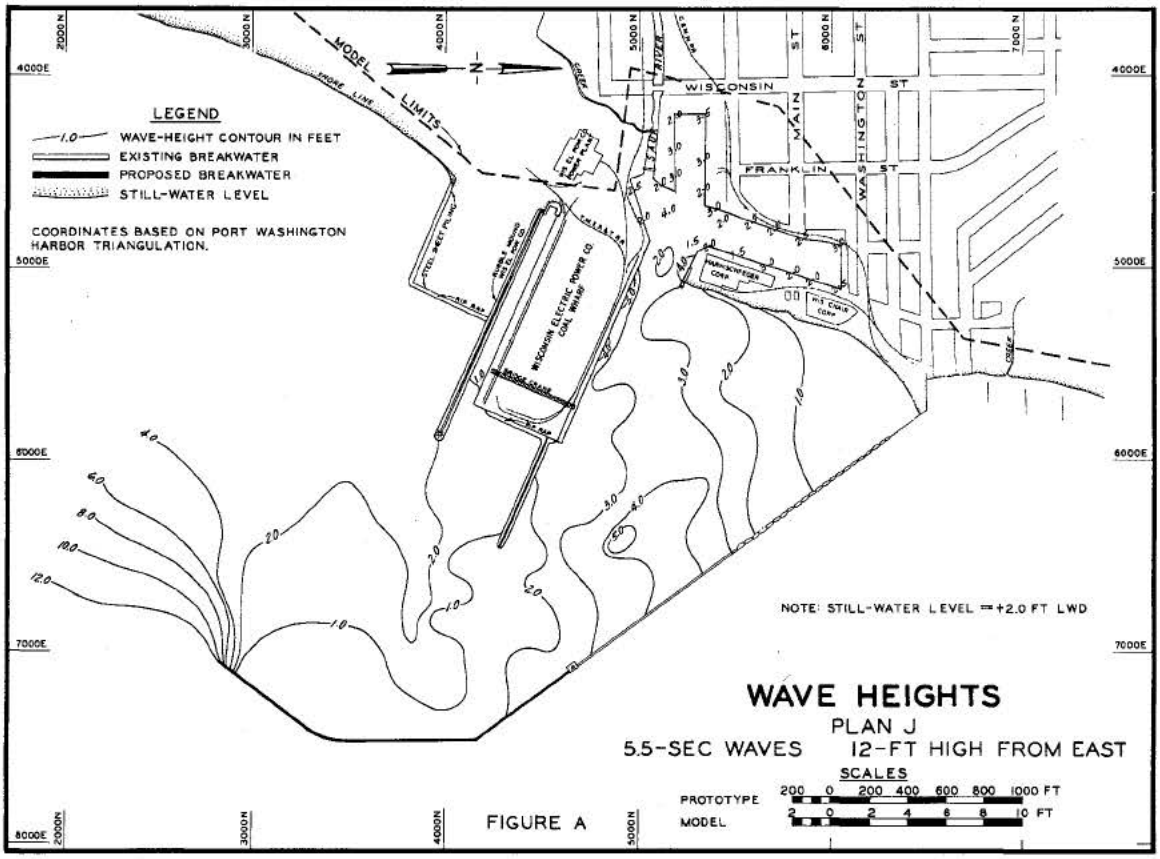


FIGURE A

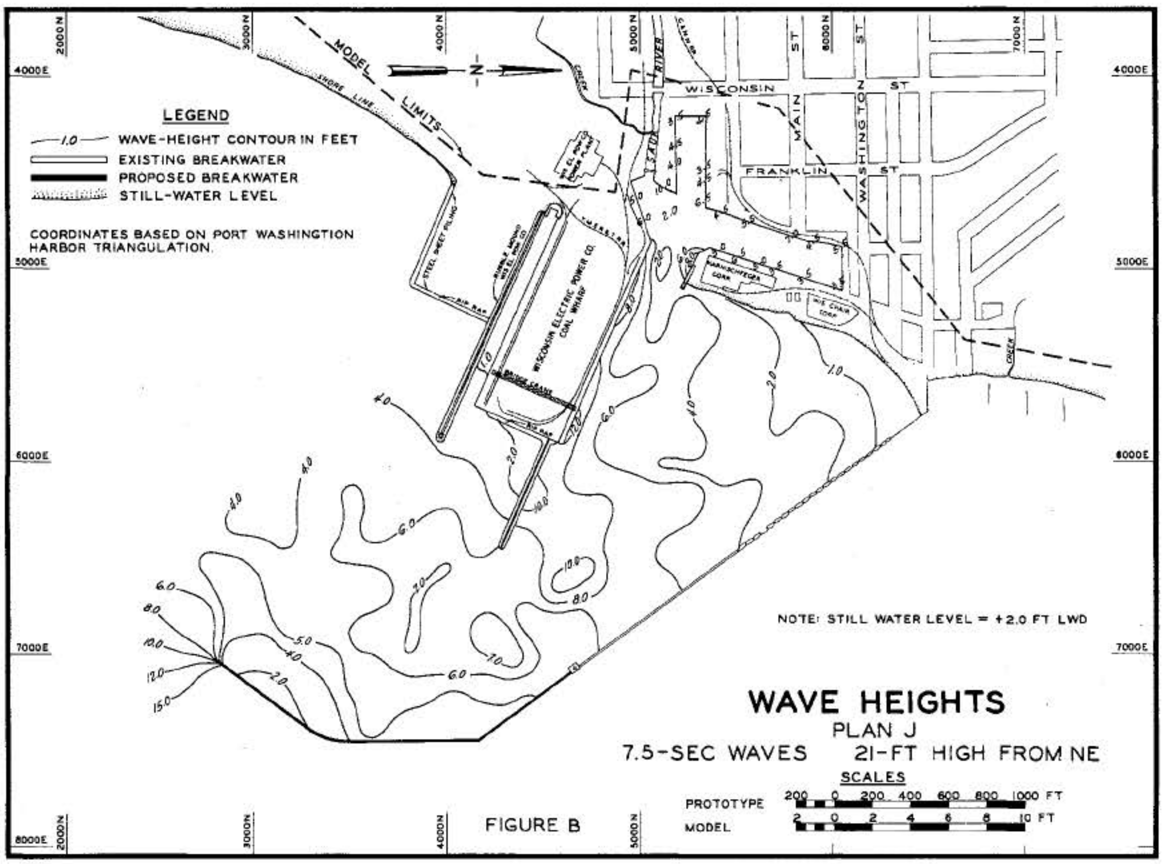
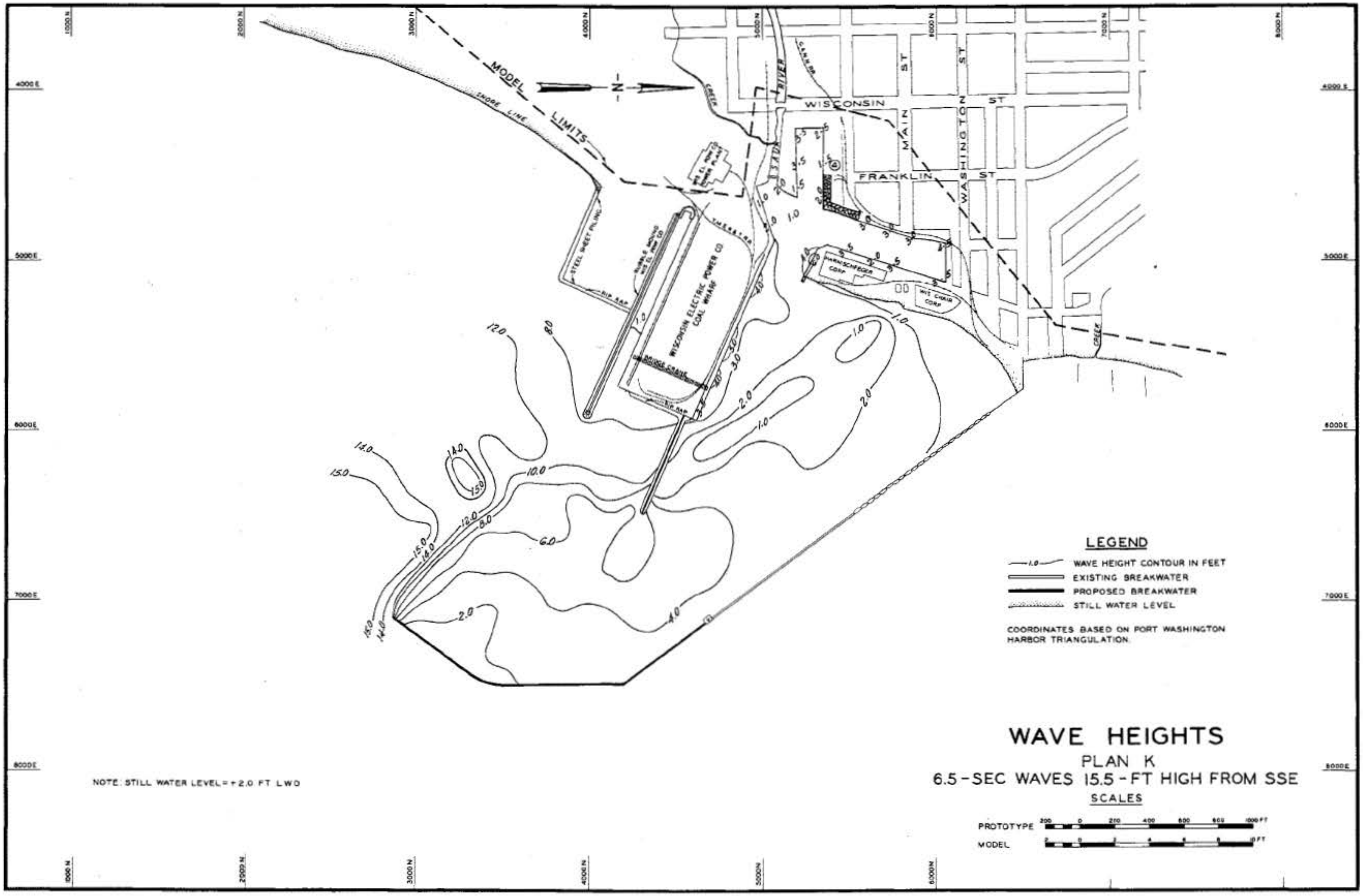


FIGURE B



WAVE HEIGHTS

PLAN K

6.5-SEC WAVES 15.5-FT HIGH FROM SSE

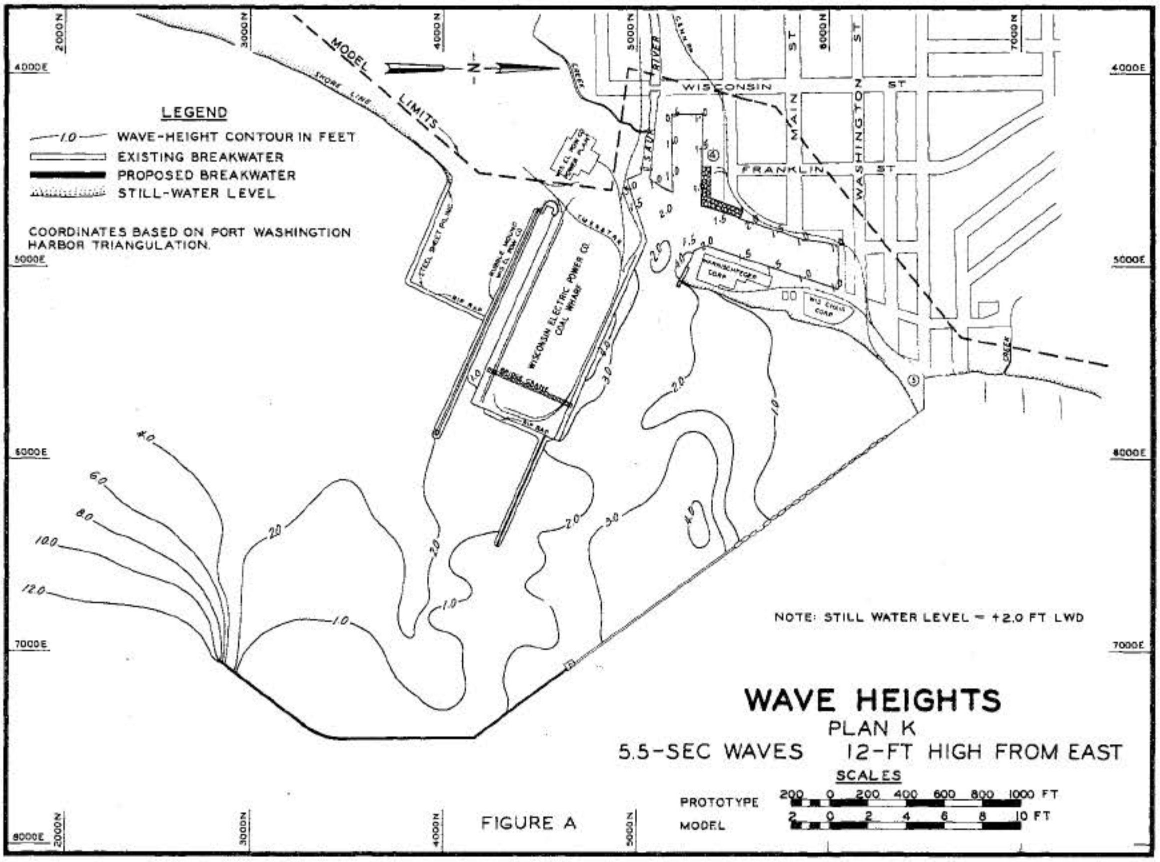


FIGURE A

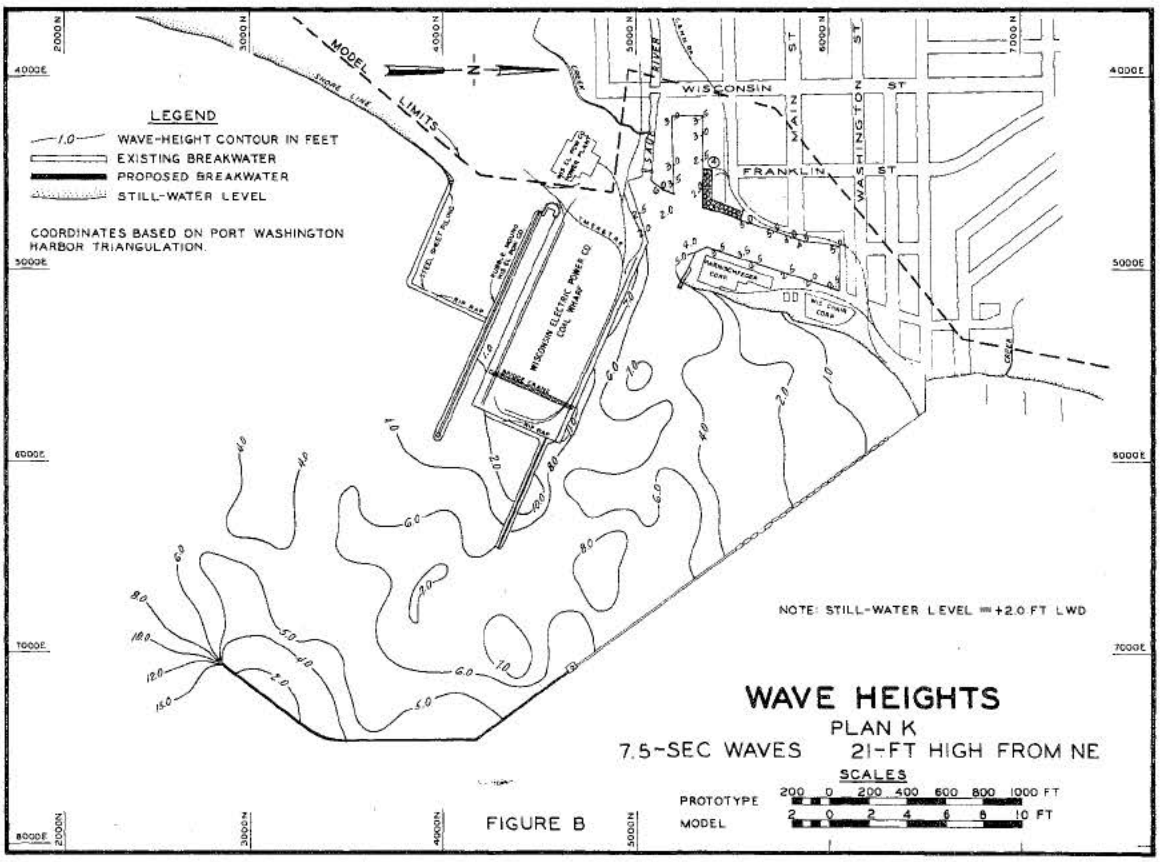
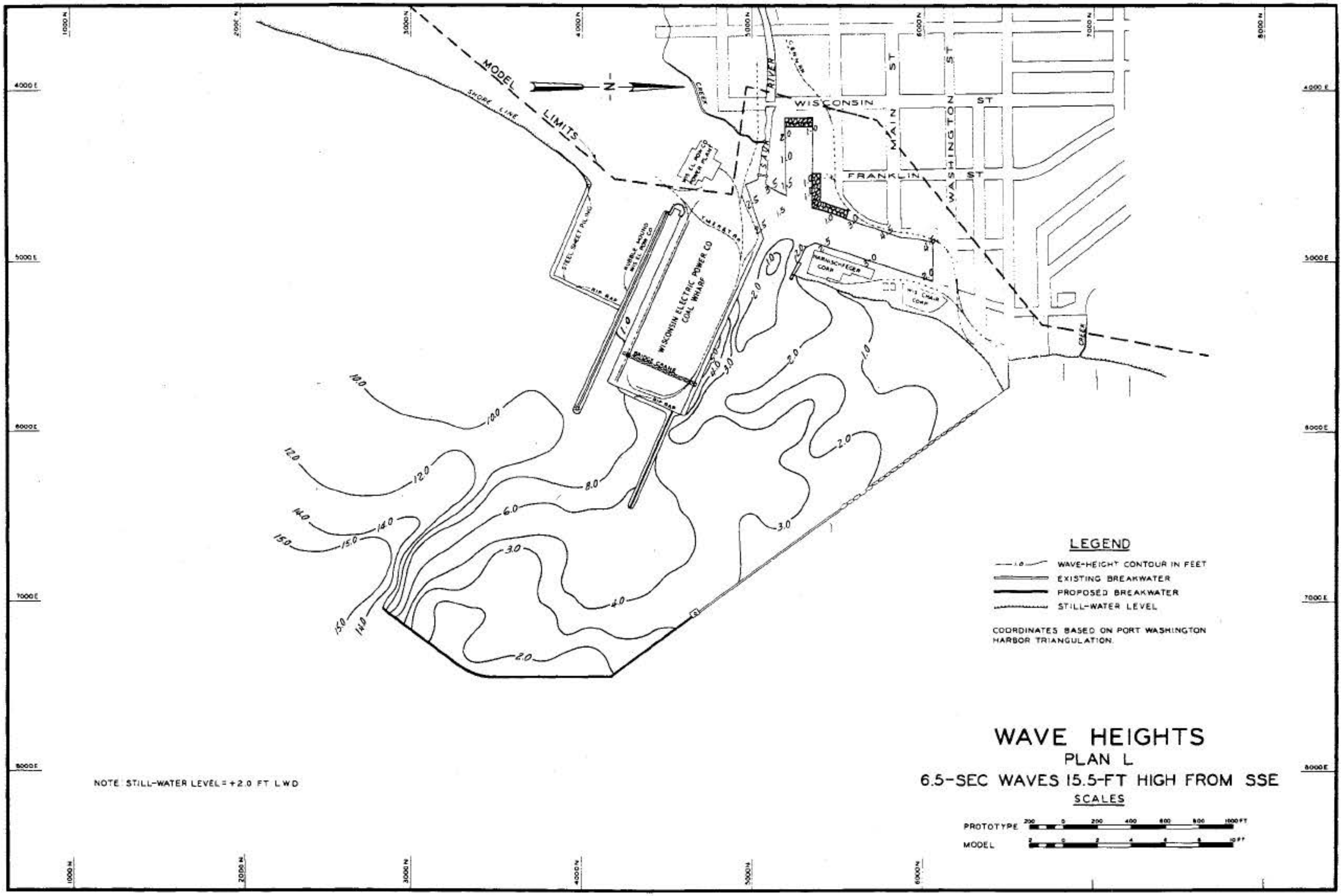
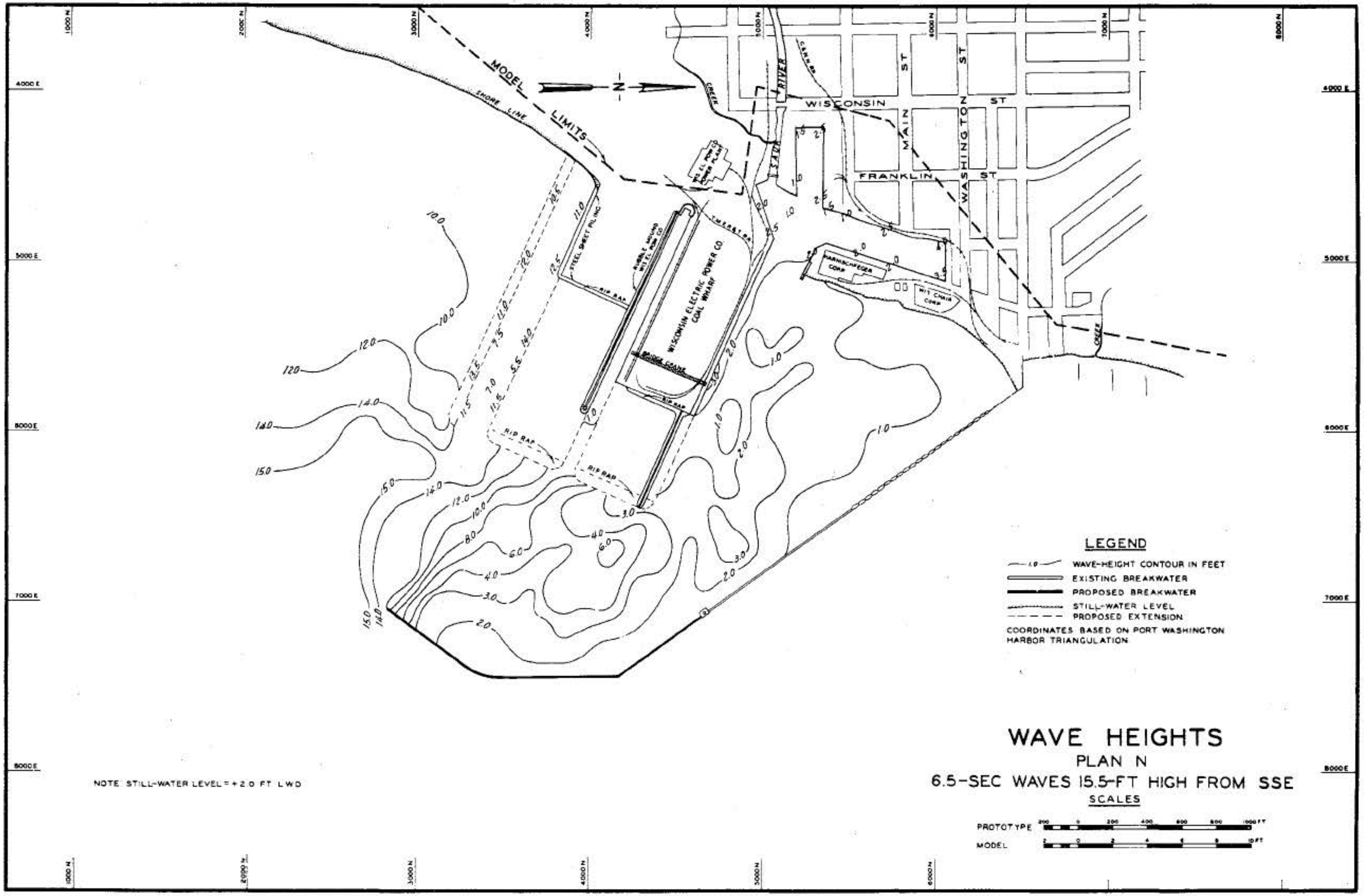


FIGURE B

PLATE 31



WAVE HEIGHTS
PLAN L
6.5-SEC WAVES 15.5-FT HIGH FROM SSE



WAVE HEIGHTS
PLAN N
6.5-SEC WAVES 15.5-FT HIGH FROM SSE

PLATE 32

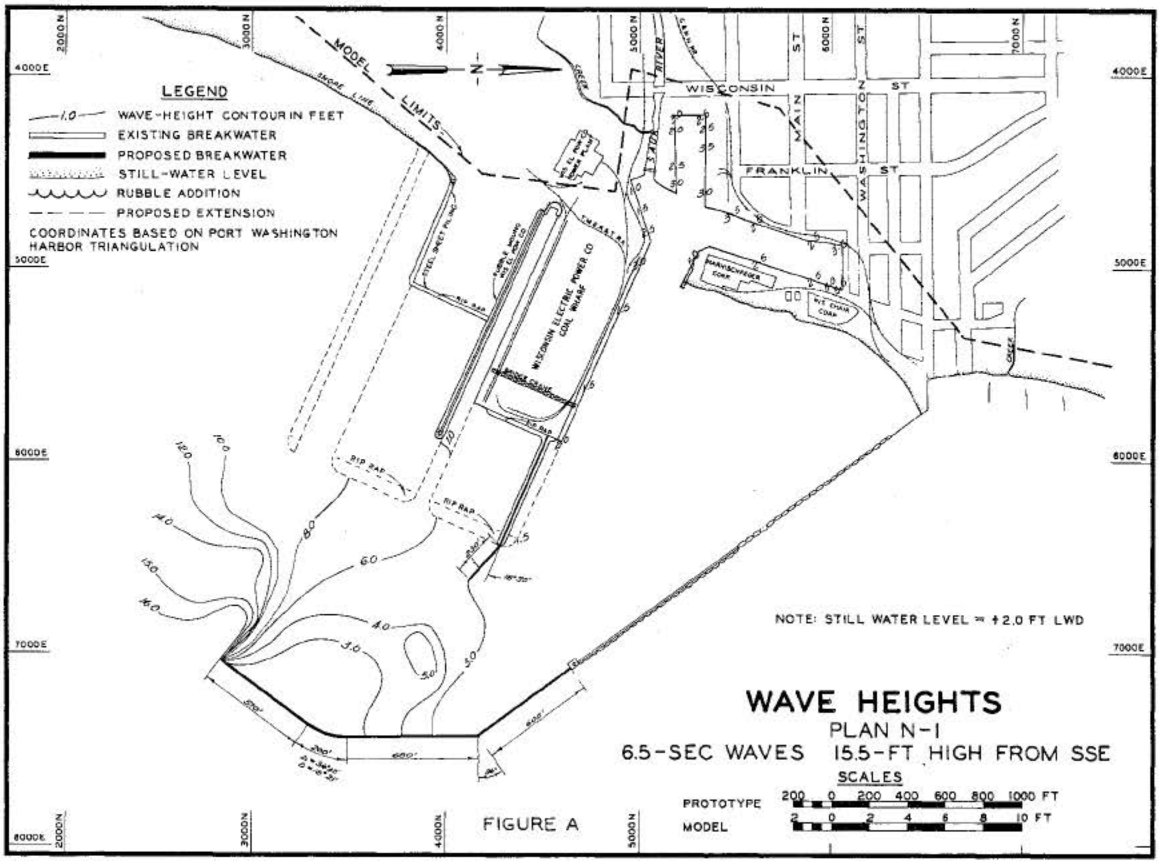


FIGURE A

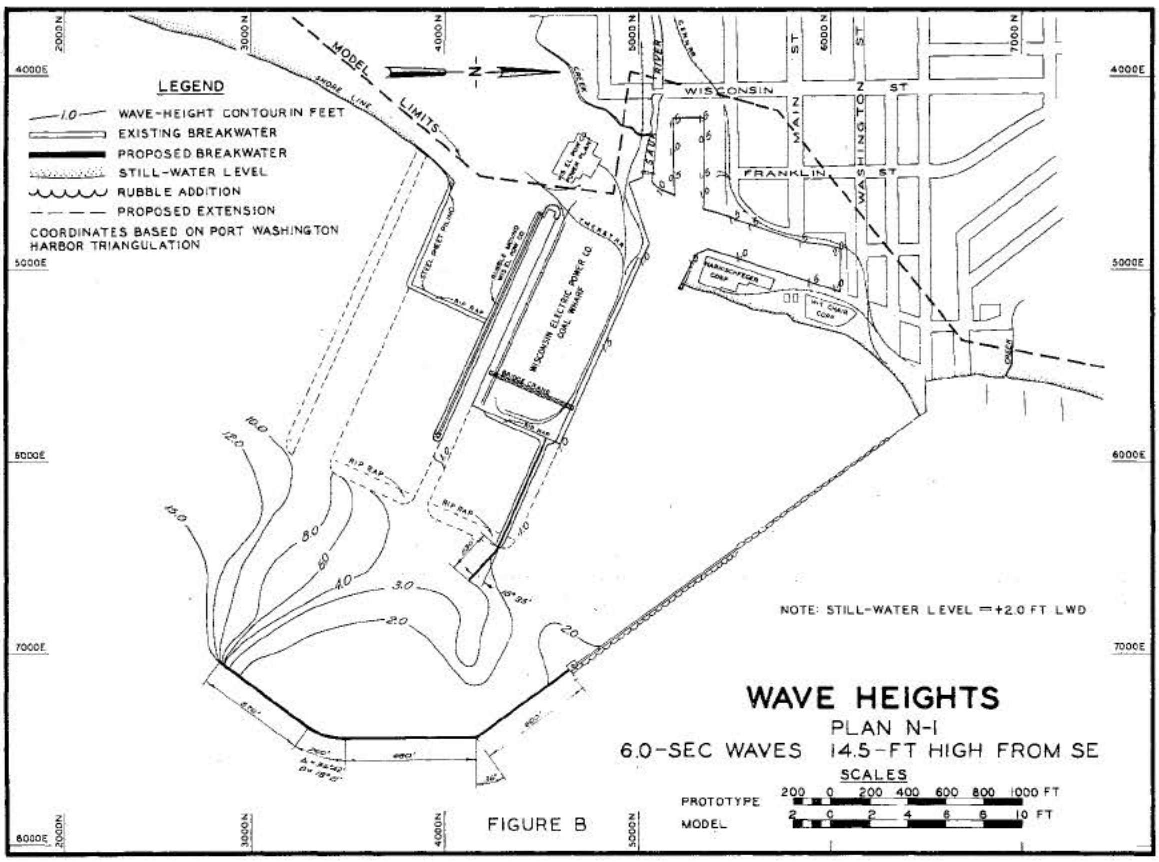
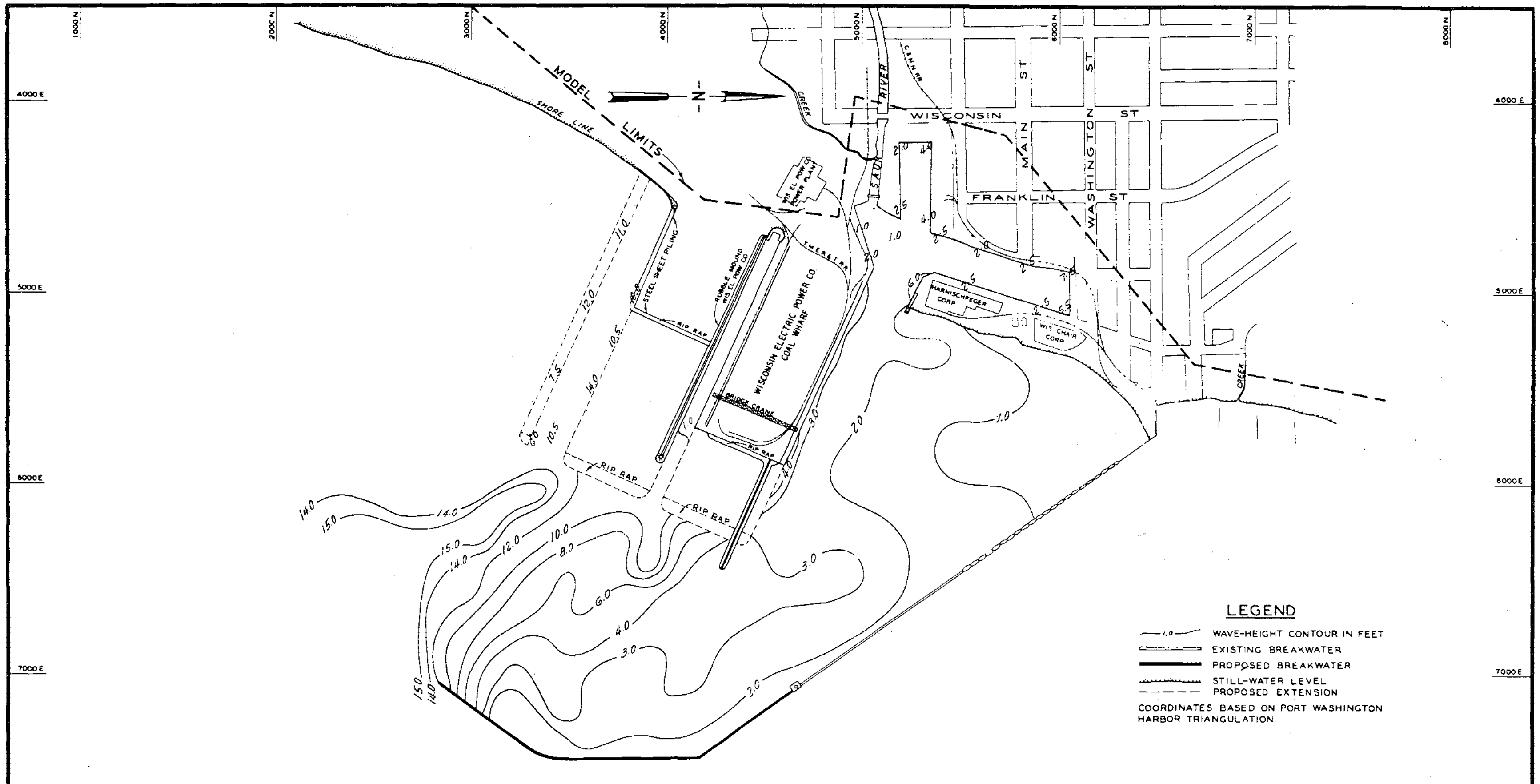


FIGURE B

PLATE 33



WAVE HEIGHTS

PLAN O

6.5-SEC WAVES 15.5-FT HIGH FROM SSE

SCALES

PROTOTYPE 200 0 200 400 600 800 1000 FT

MODEL 2 0 2 4 6 8 10 FT

NOTE: STILL-WATER LEVEL = +2.0 FT LWD

PLATE 34

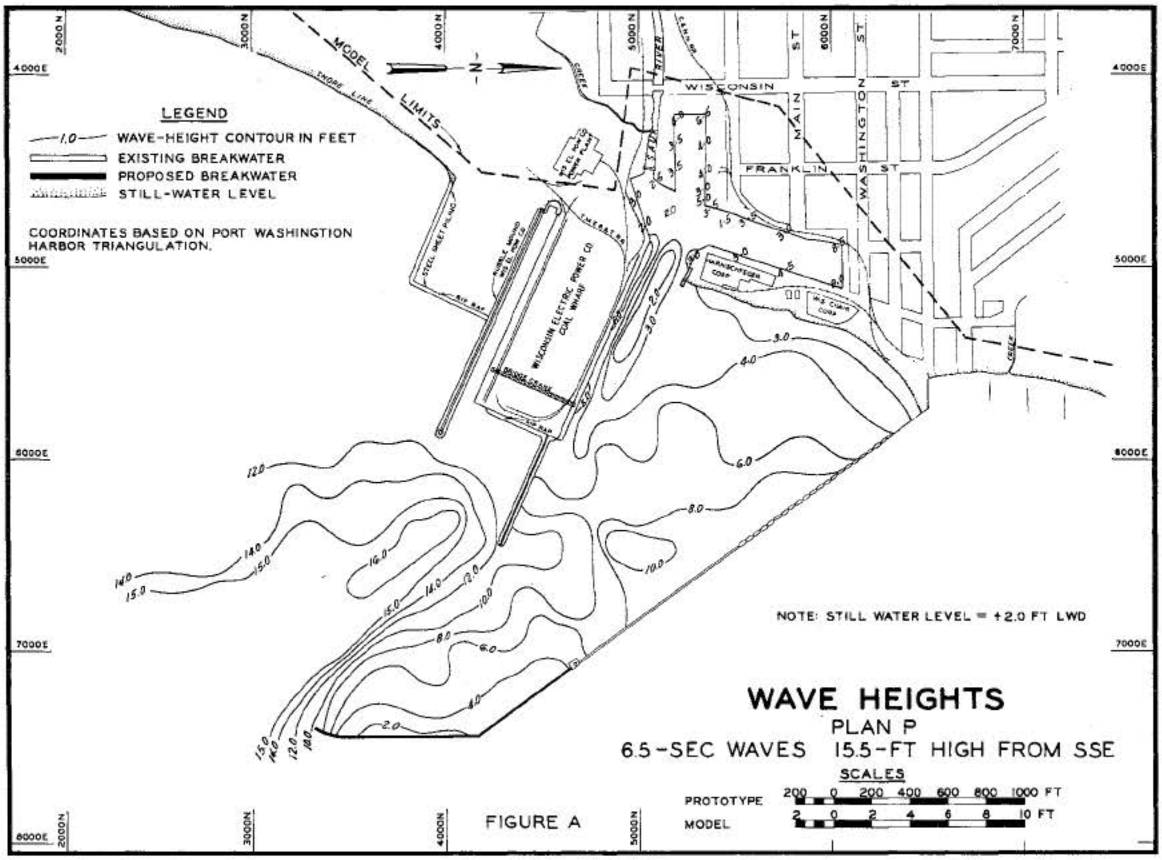


FIGURE A

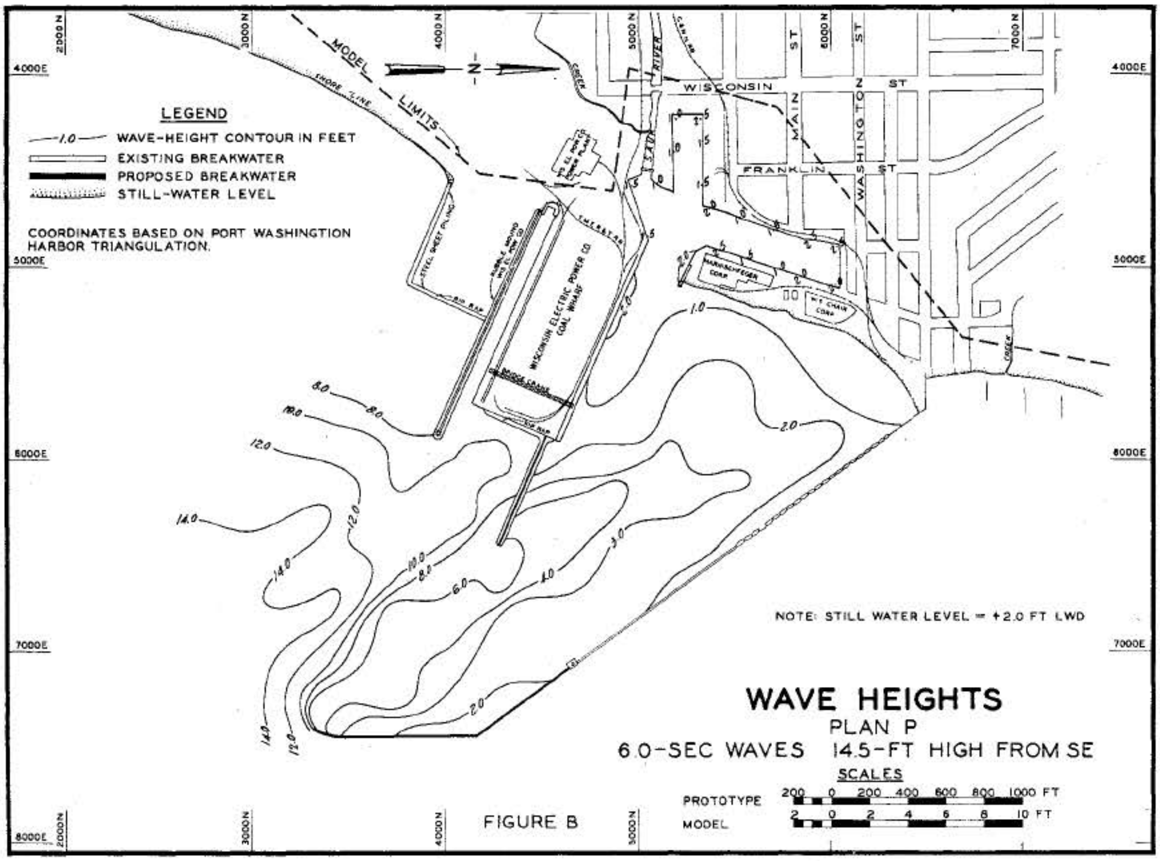


FIGURE B

PLATE 35

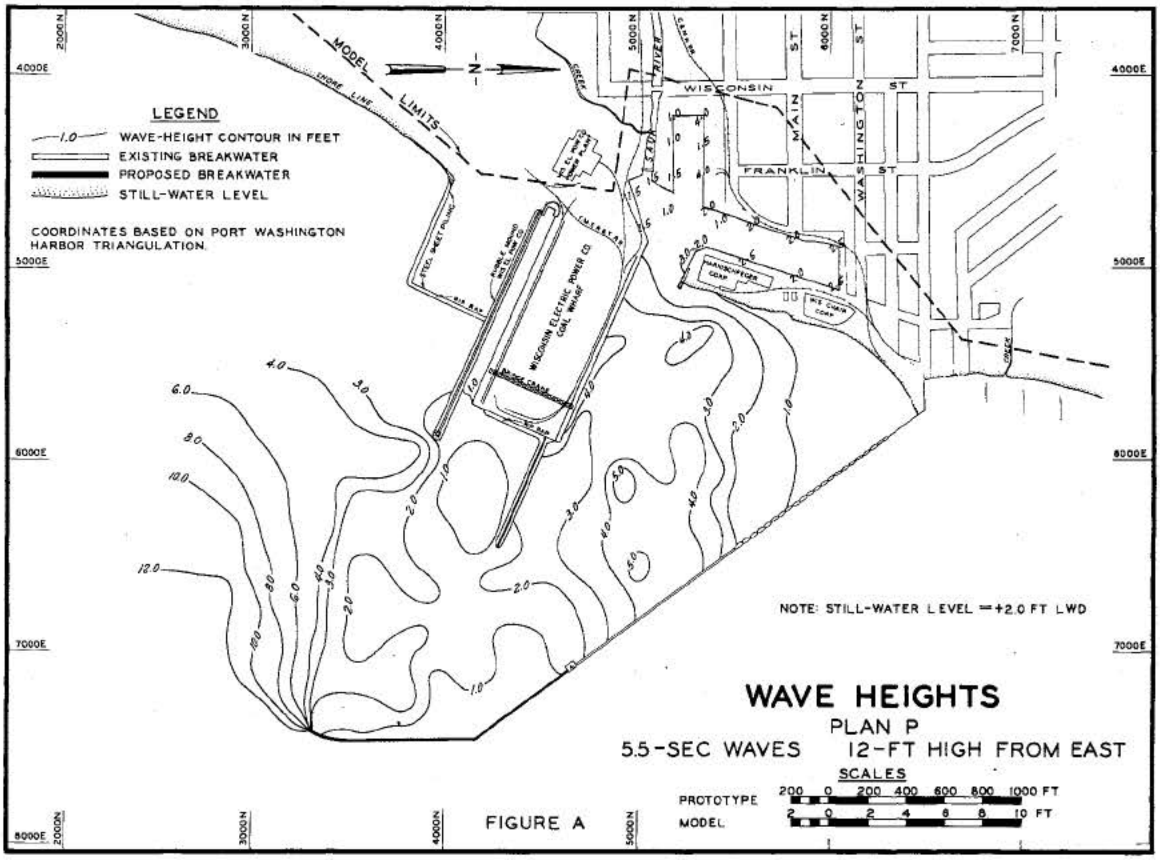


FIGURE A

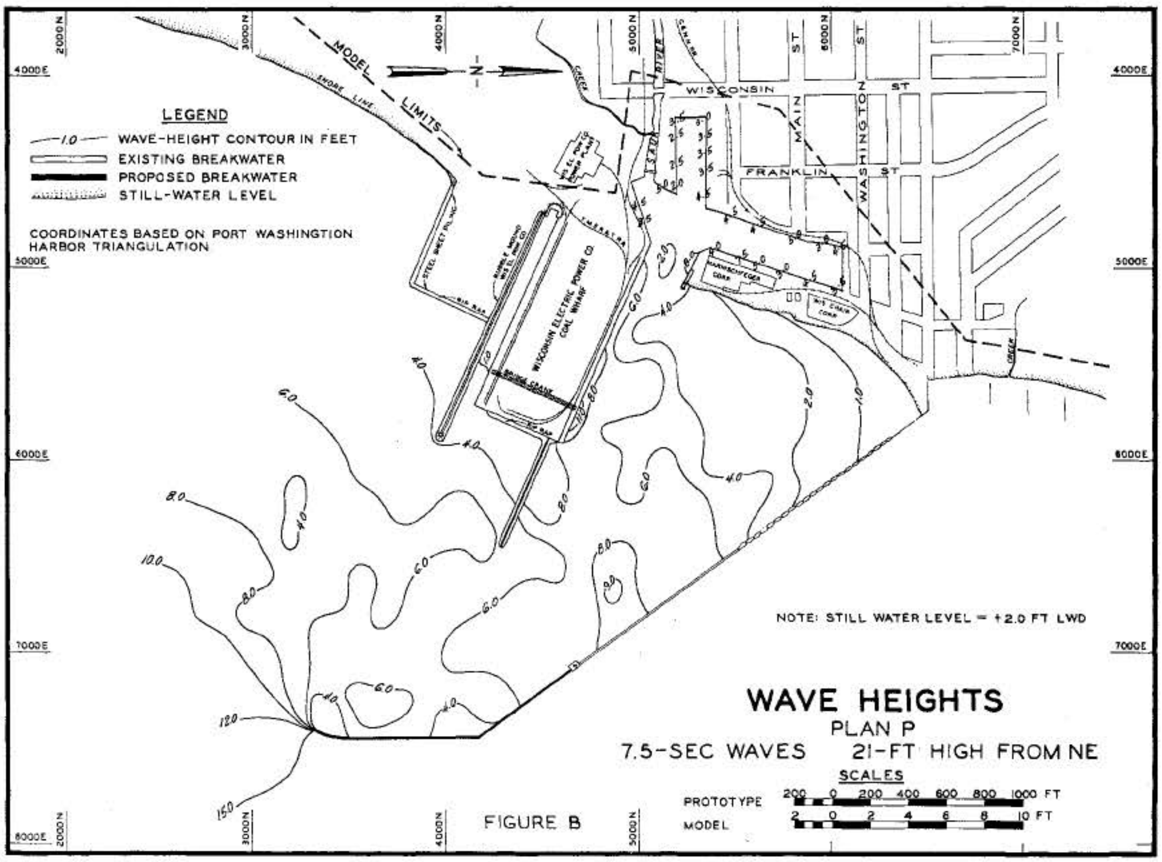


FIGURE B

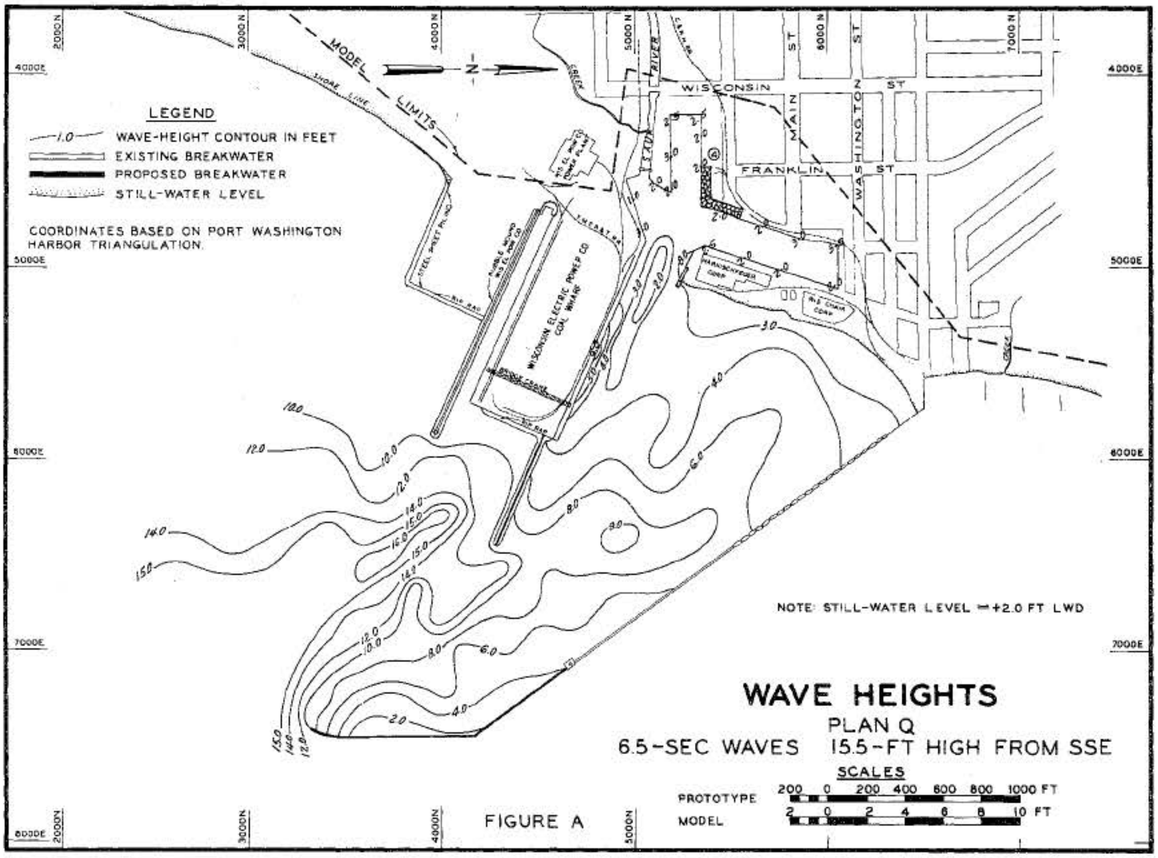


FIGURE A

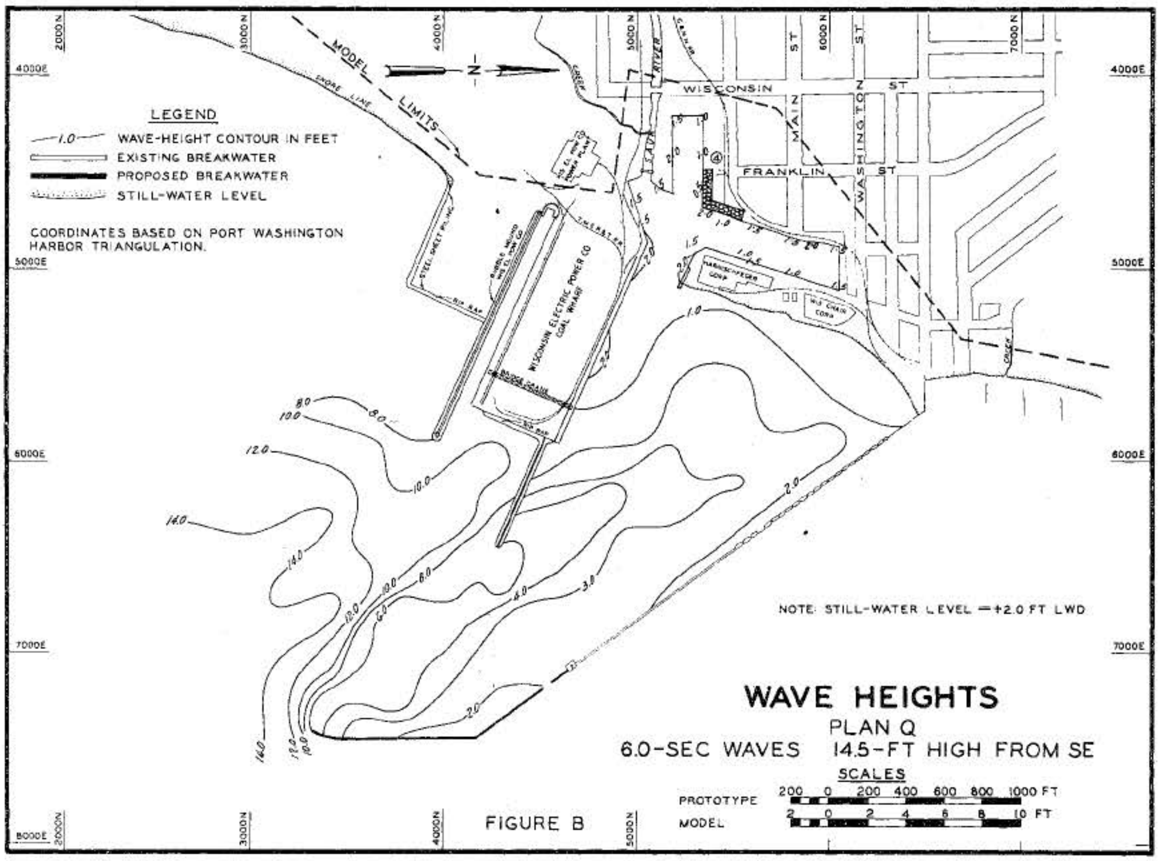


FIGURE B

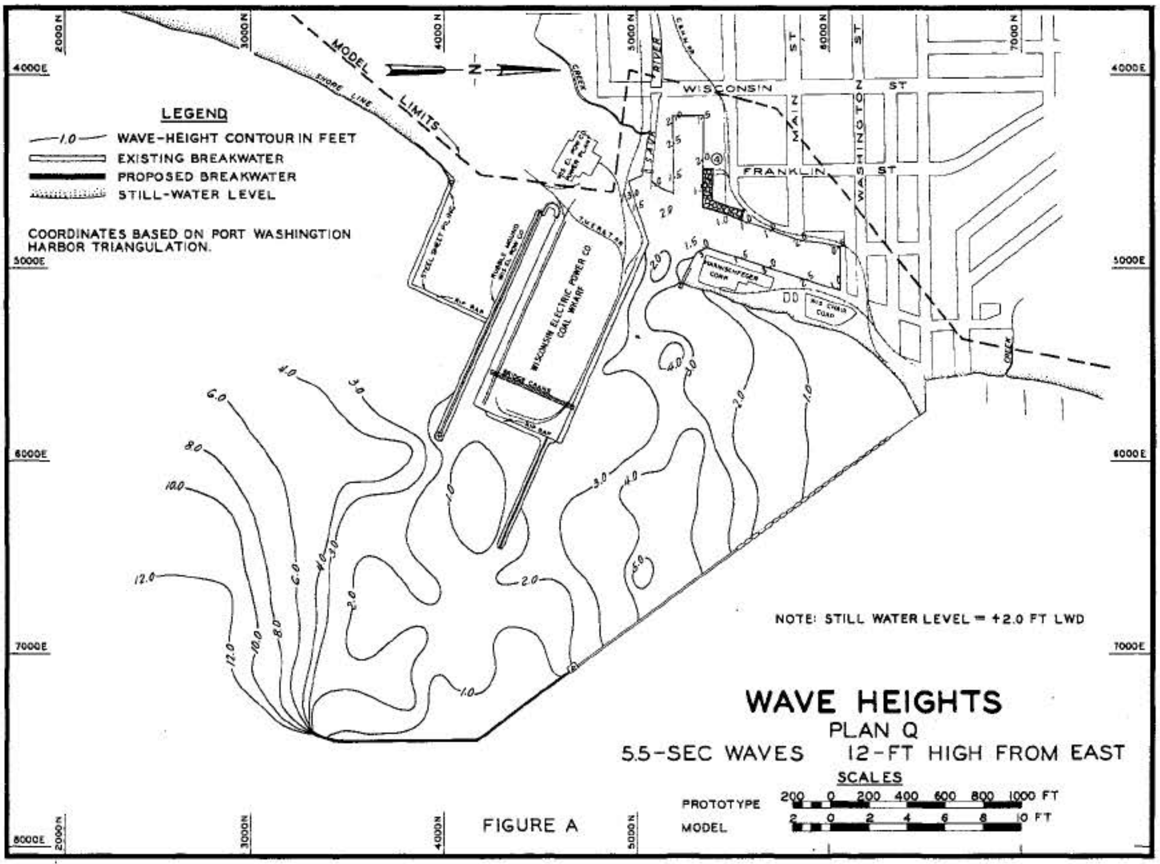


FIGURE A

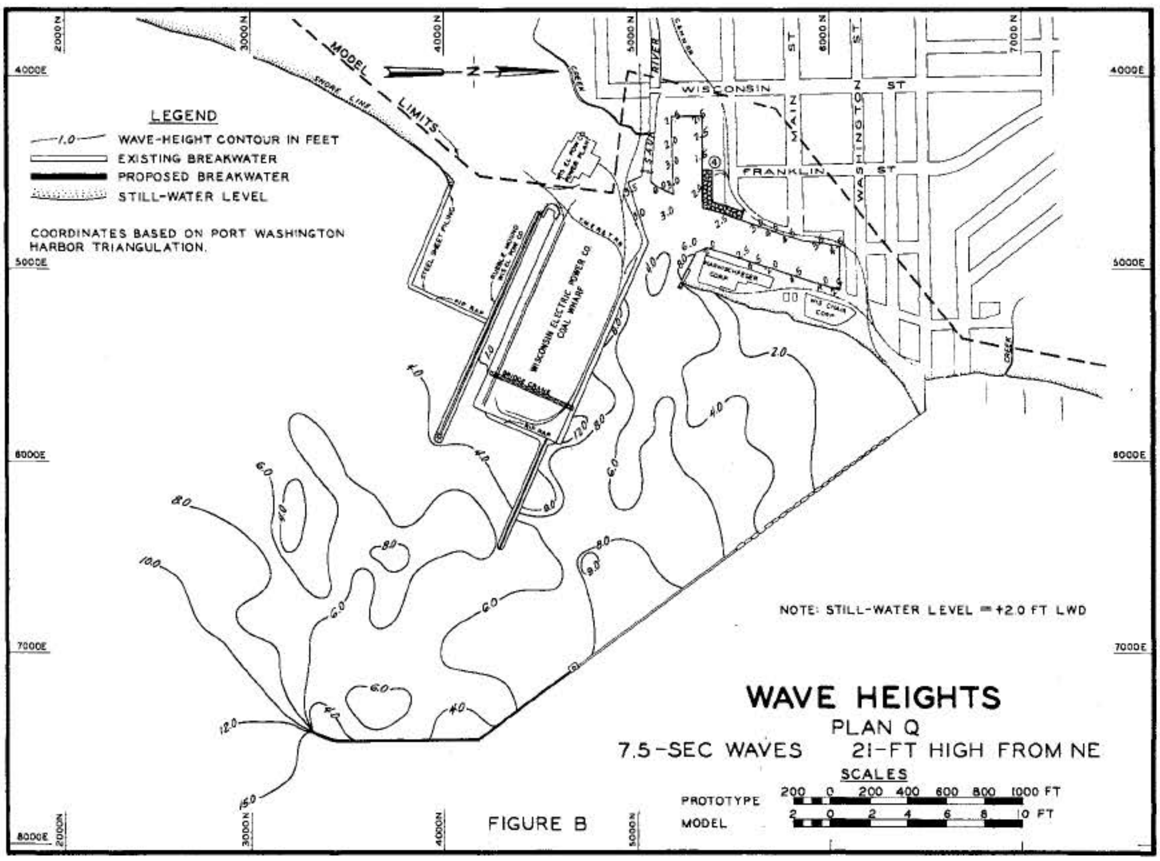
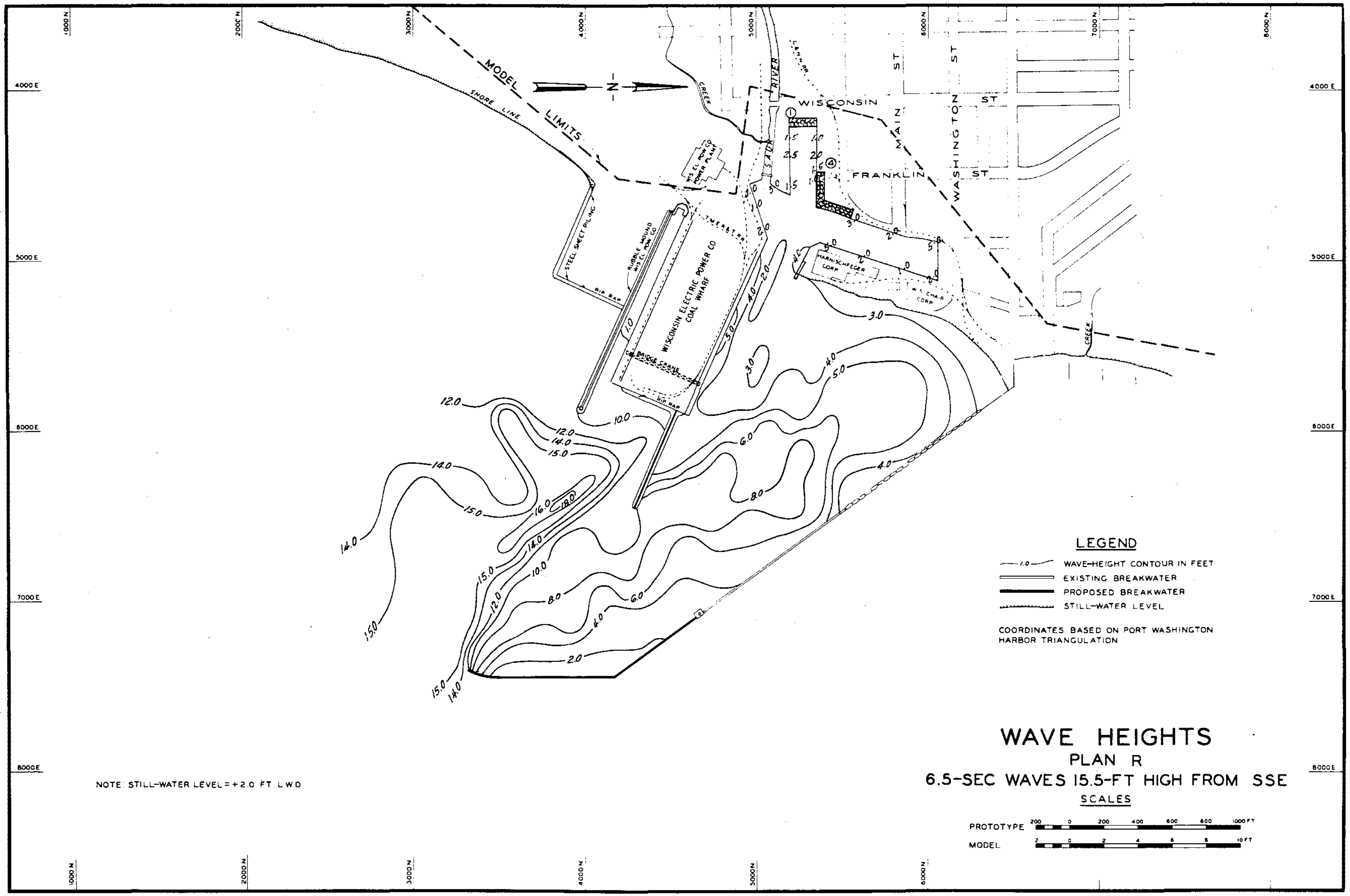
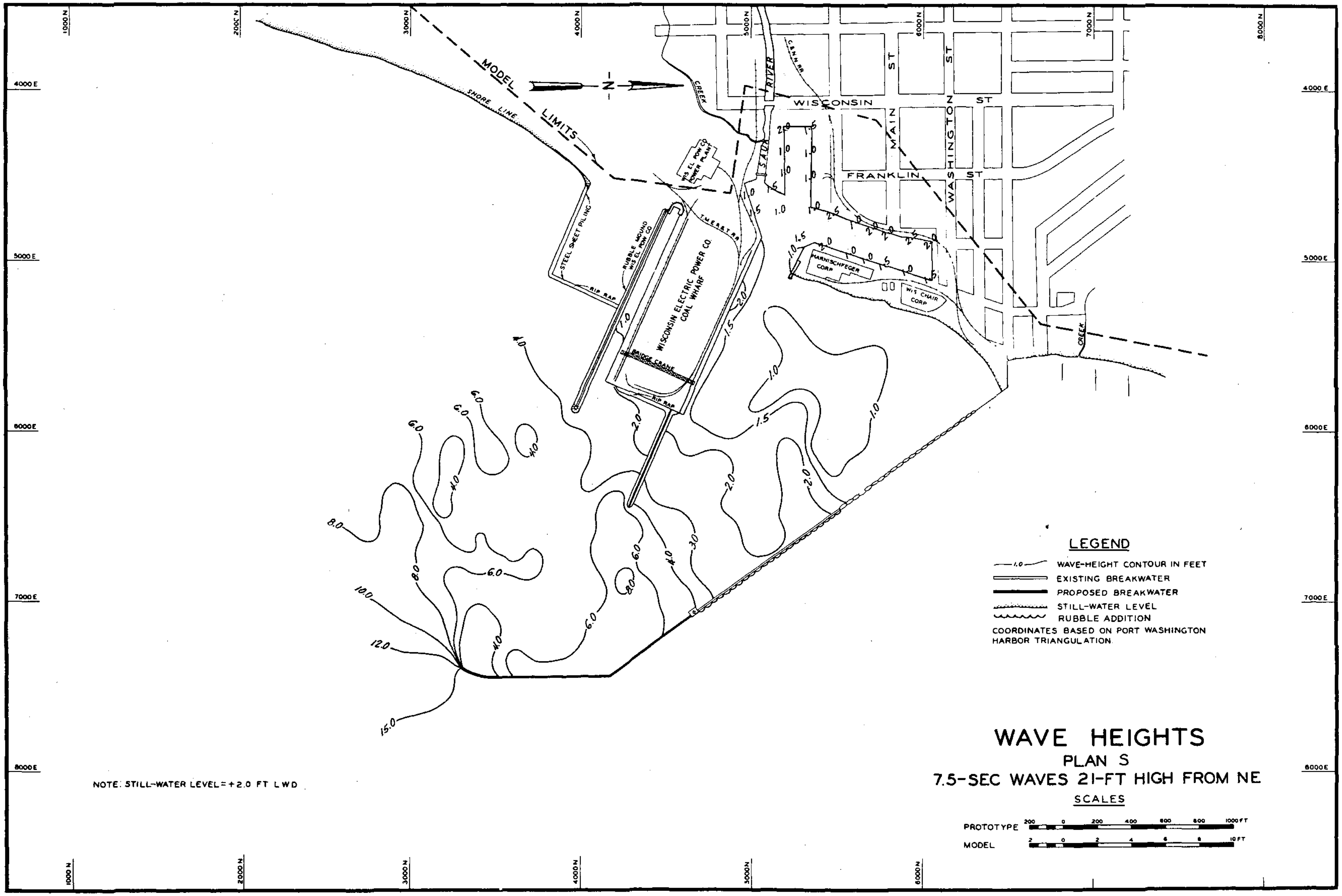


FIGURE B

PLATE 39



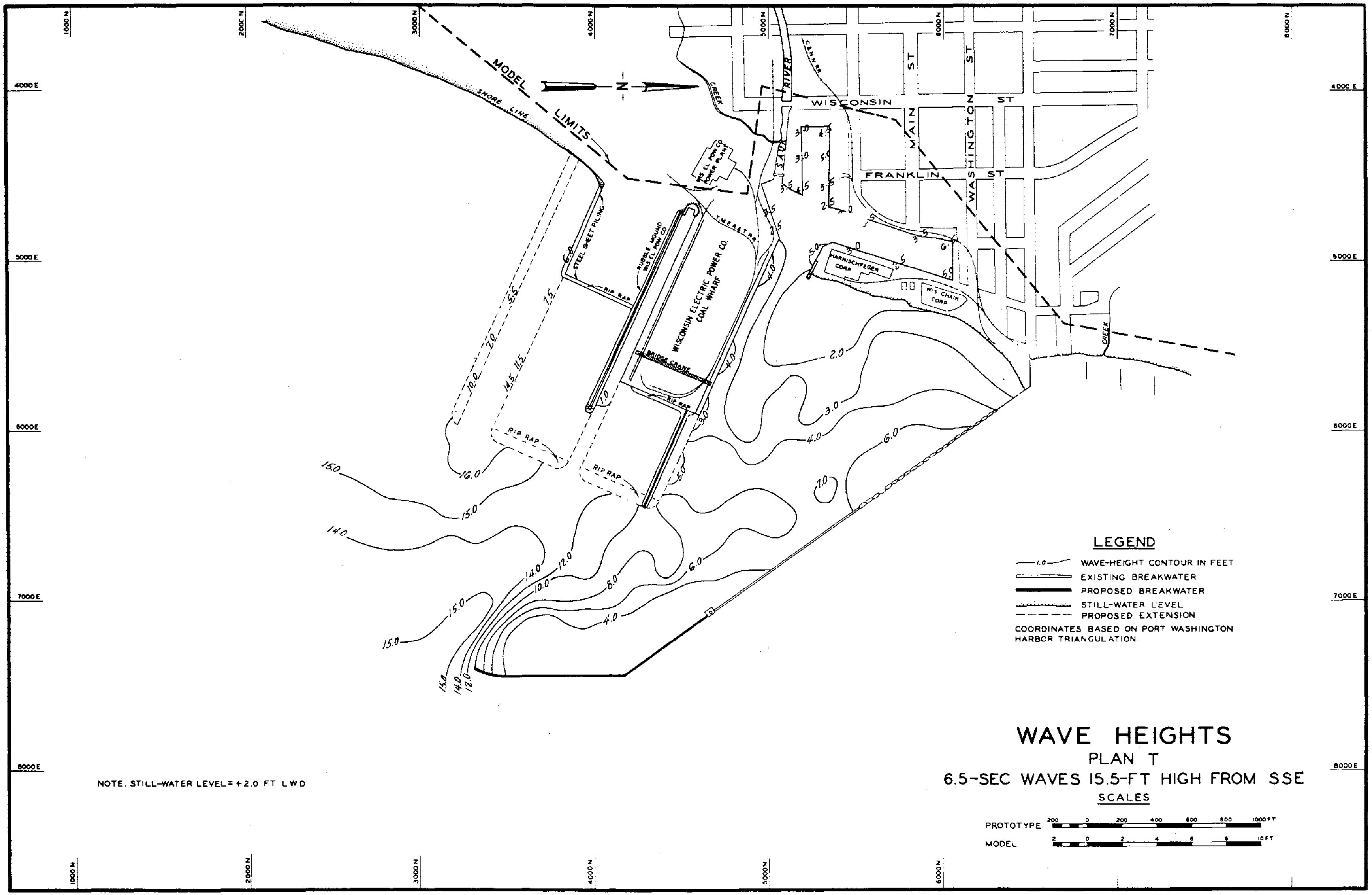
WAVE HEIGHTS
PLAN R
6.5-SEC WAVES 15.5-FT HIGH FROM SSE



WAVE HEIGHTS
PLAN S
7.5-SEC WAVES 21-FT HIGH FROM NE

PLATE 40

PLATE 41



WAVE HEIGHTS

PLAN T

6.5-SEC WAVES 15.5-FT HIGH FROM SSE

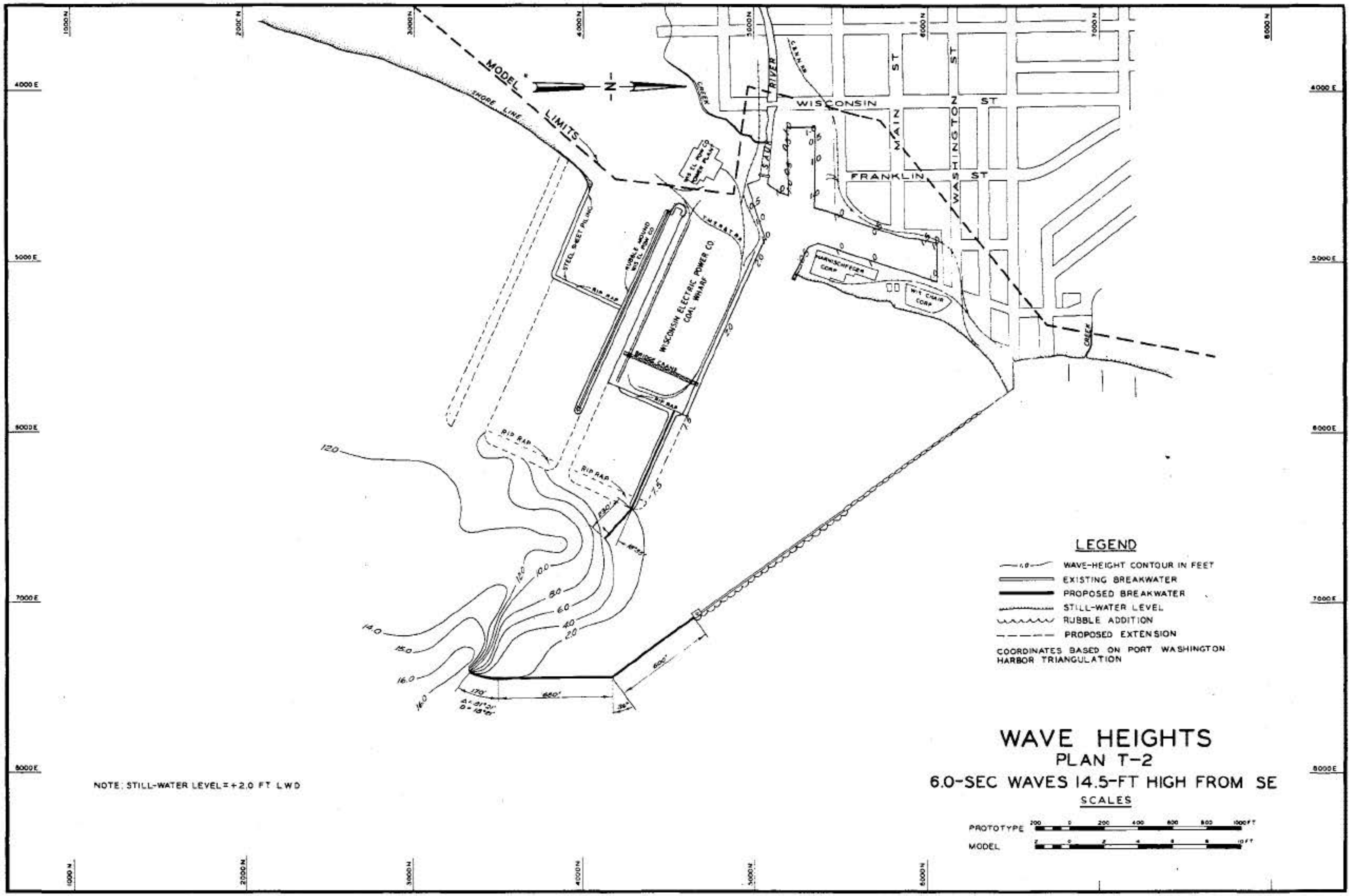
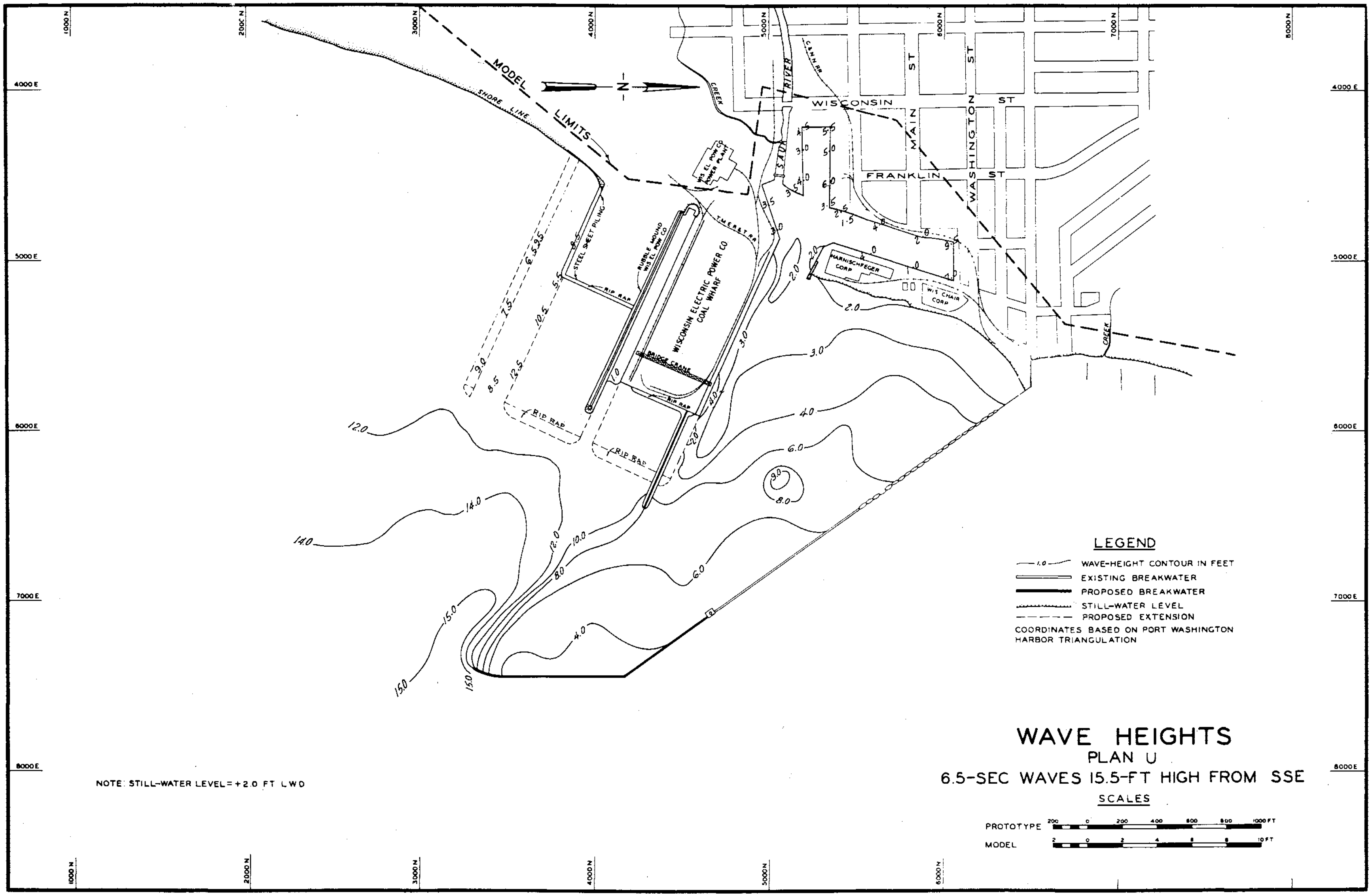

WAVE HEIGHTS
PLAN T-2
6.0-SEC WAVES 14.5-FT HIGH FROM SE
SCALES
PROTOTYPE
MODEL
LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
PROPOSED EXTENSION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
MODEL LIMITS
SHORE LINE
N
WISCONSIN ST
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
CREEK
WISCONSIN ELECTRIC POWER CO COAL WHARF
RIP RAP
STEEL SHEET PILING
4000 E
5000 E
6000 E
7000 E
8000 E
1000 N
2000 N
3000 N
4000 N
5000 N
6000 N
7000 N
8000 N

PLATE 42

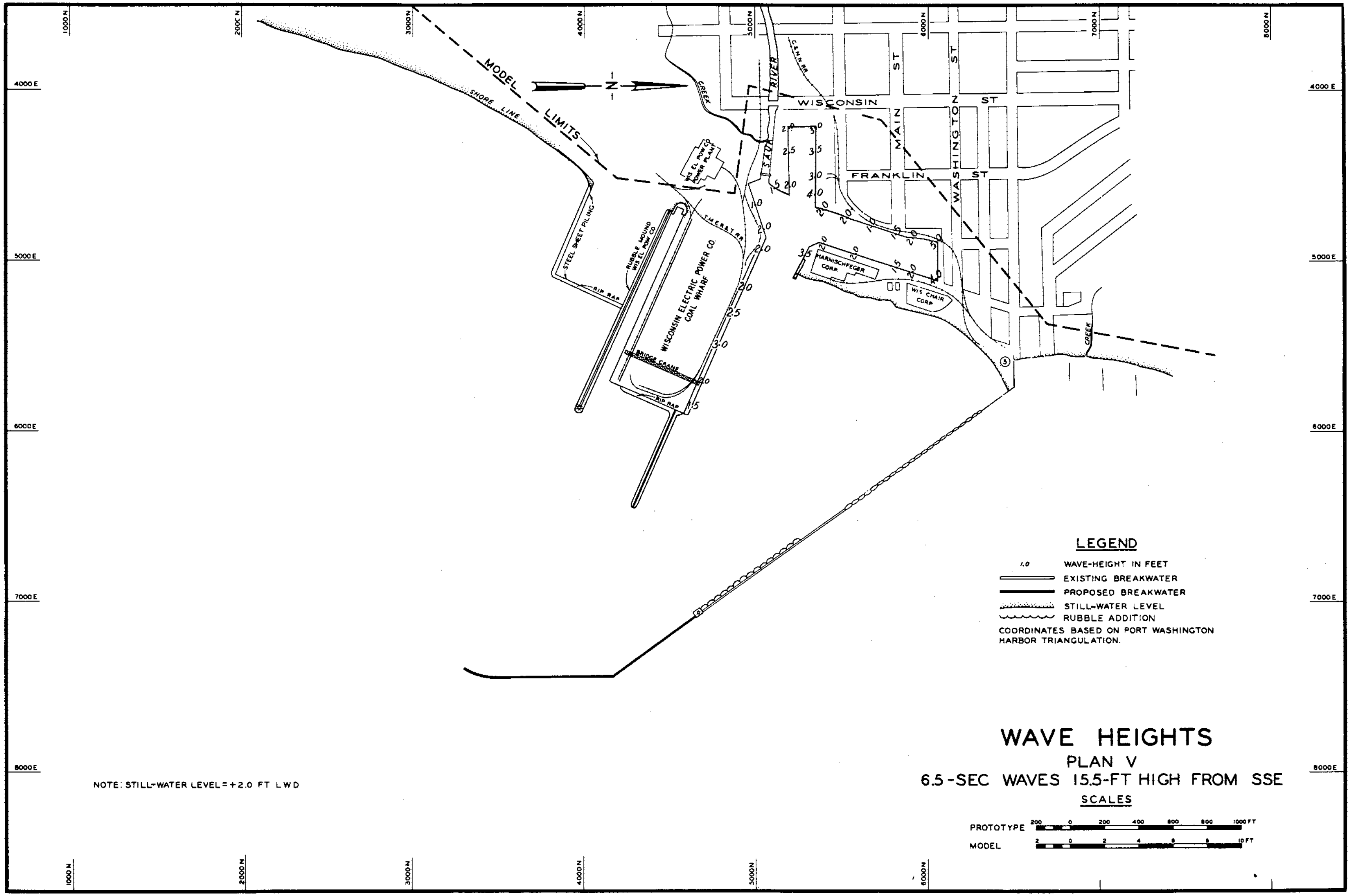
PLATE 43



WAVE HEIGHTS

PLAN U

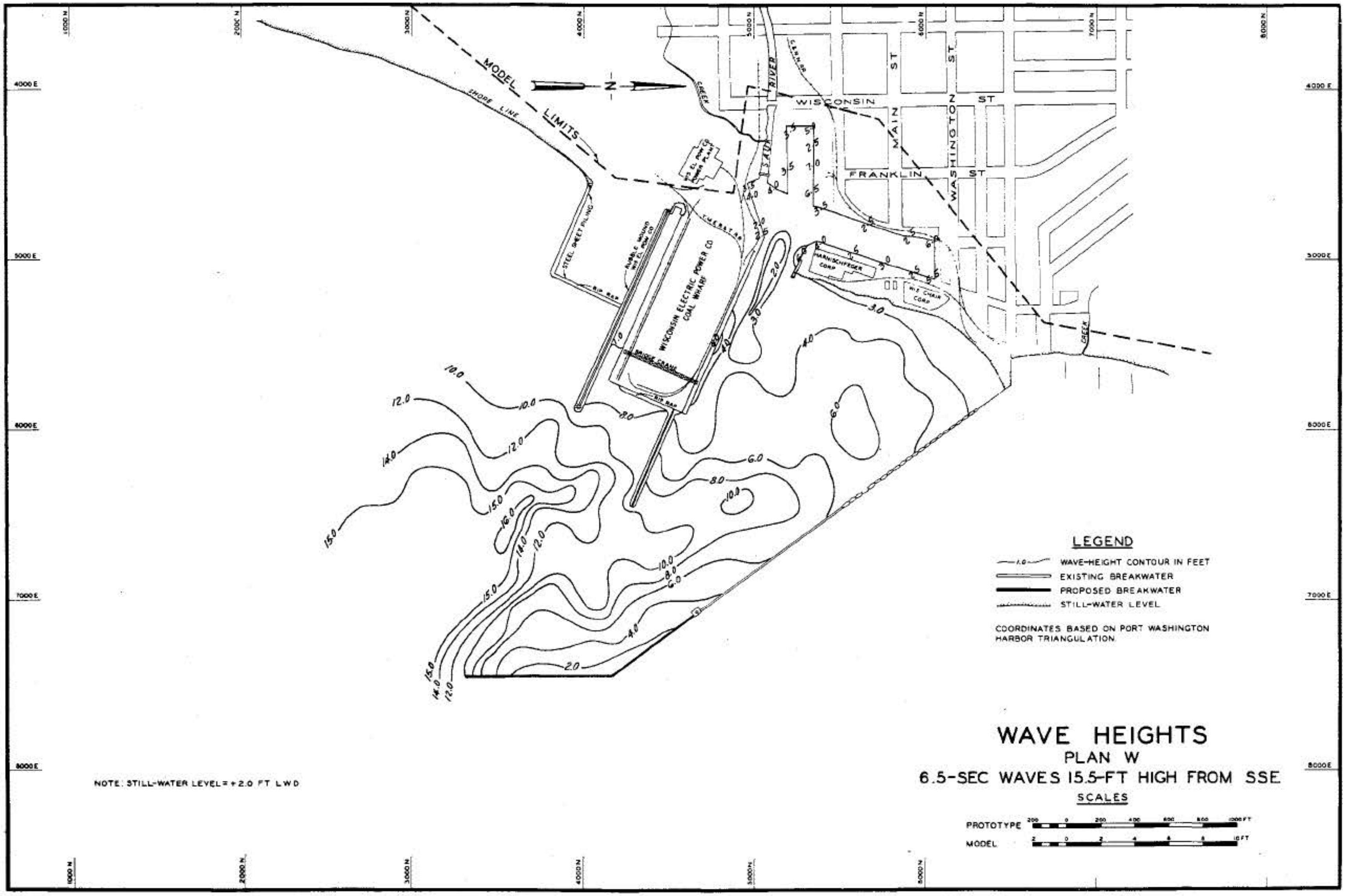
6.5-SEC WAVES 15.5-FT HIGH FROM SSE



WAVE HEIGHTS
PLAN V
6.5-SEC WAVES 15.5-FT HIGH FROM SSE

PLATE 44

PLATE 45


WAVE HEIGHTS
PLAN W
6.5-SEC WAVES 15.5-FT HIGH FROM SSE
SCALES
PROTOTYPE
MODEL
LEGEND
WAVE-HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION.
NOTE: STILL-WATER LEVEL = +2.0 FT LWD
MODEL LIMITS
SHORE LINE
STEEL SHEET PILING
WISCONSIN ELECTRIC POWER CO. COAL WHARF
BRIDGE CRANE
RIP RAP
RUBBLE MOUND
WISCONSIN
FRANKLIN
ST
MAIN ST
WASHINGTON ST
SAUK RIVER
CREEK
HARNISCHFEGER CORP
WIS CHAIR CORP
N
4000 E
5000 E
6000 E
7000 E
8000 E
1000 N
2000 N
3000 N
4000 N
5000 N
6000 N
7000 N
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2.0
3.0
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10.0
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14.0
15.0
16.0

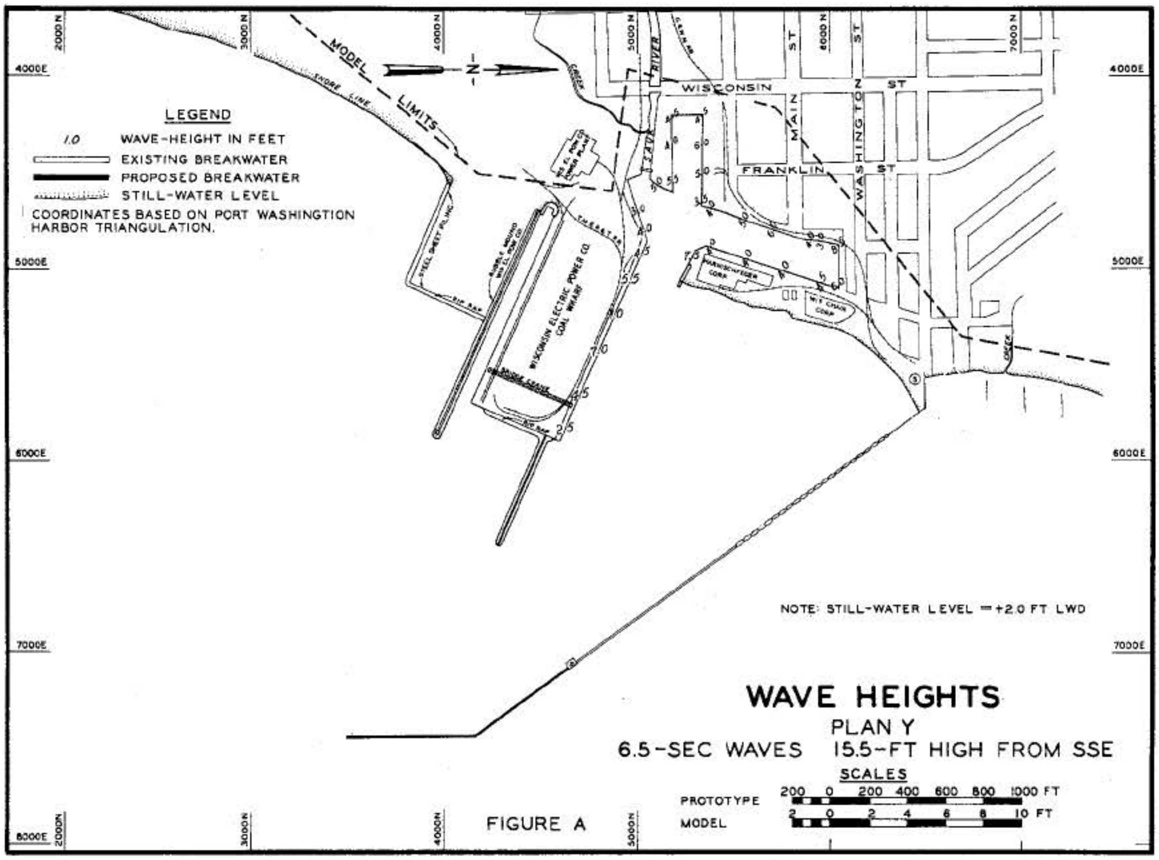


FIGURE A

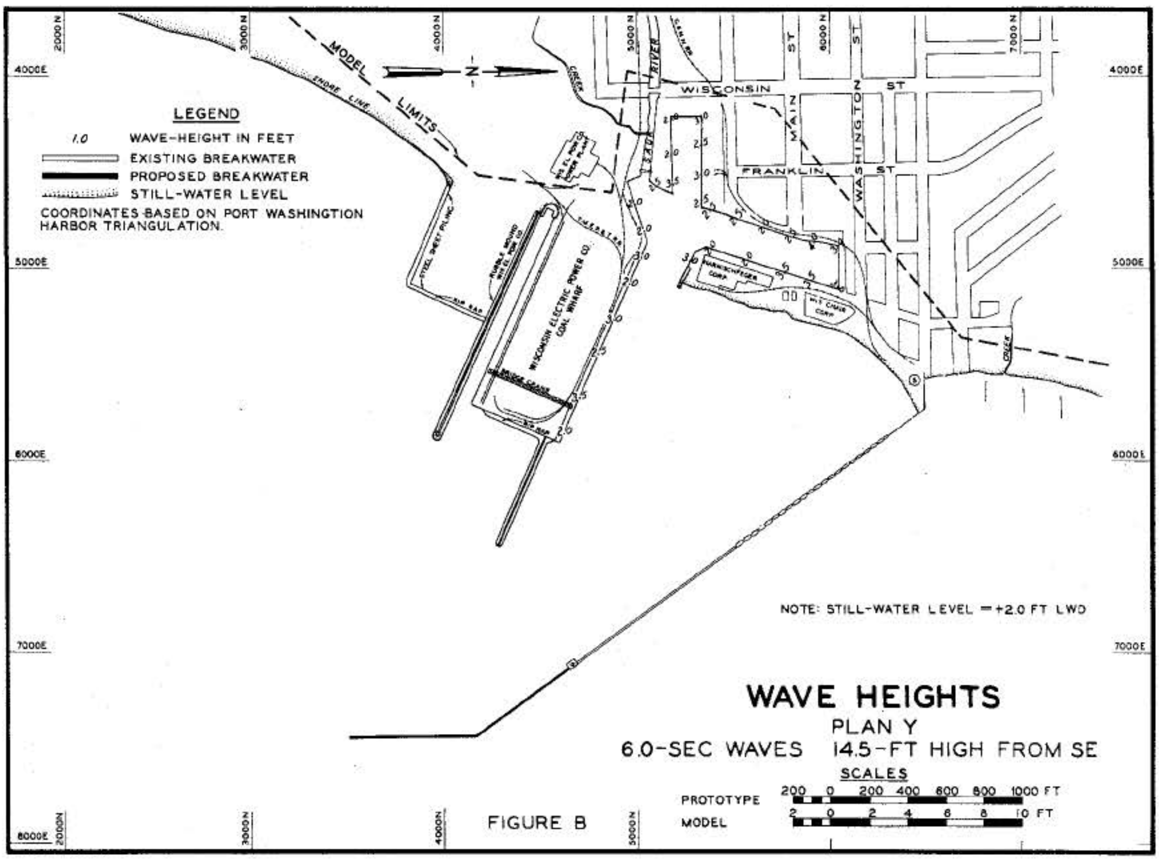
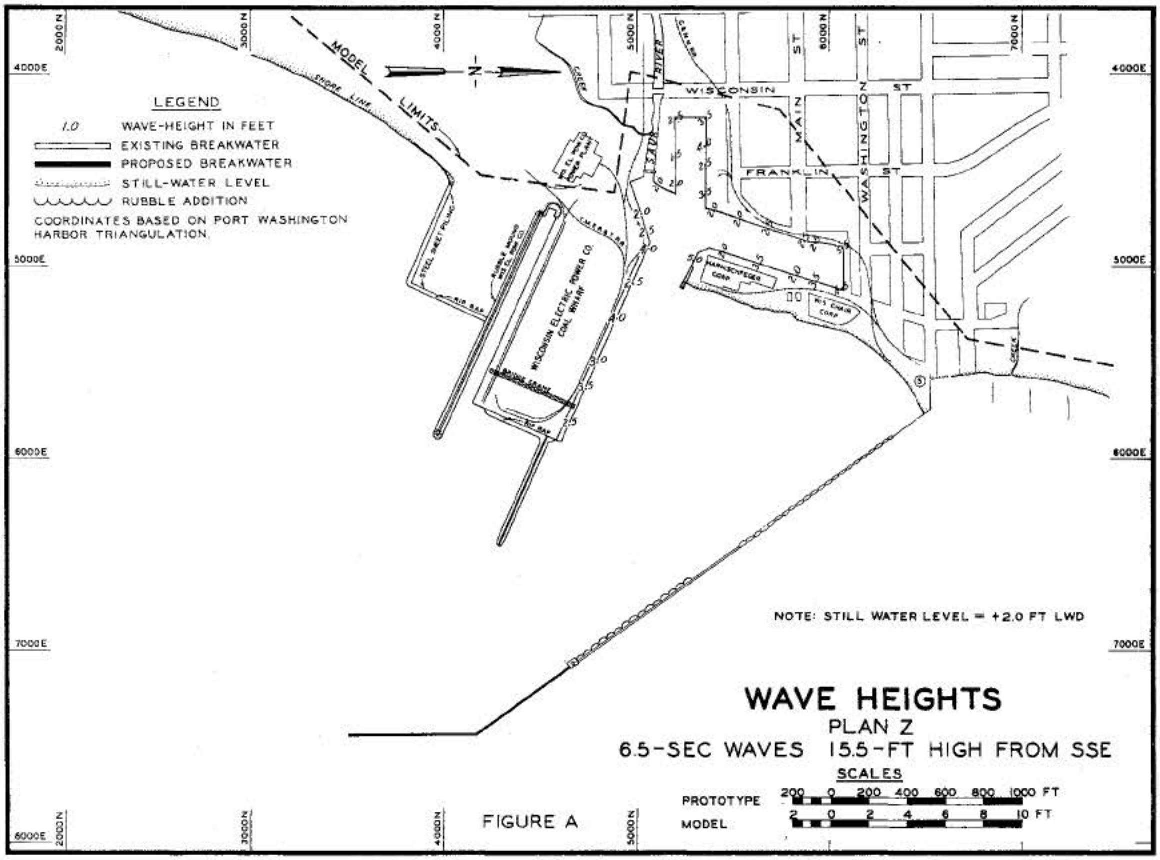


FIGURE B


LEGEND
1.0 WAVE-HEIGHT IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION.
MODEL LIMITS
SHORE LINE
N
WISCONSIN
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
WISCONSIN ELECTRIC POWER CO. COAL WHARF
STEEL SHEET PILING
RIP RAP
BRIDGE CRANE
HARNISCHFEGER CORP
WIS CHAIR CORP
NOTE: STILL WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN Z
6.5-SEC WAVES 15.5-FT HIGH FROM SSE
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE A

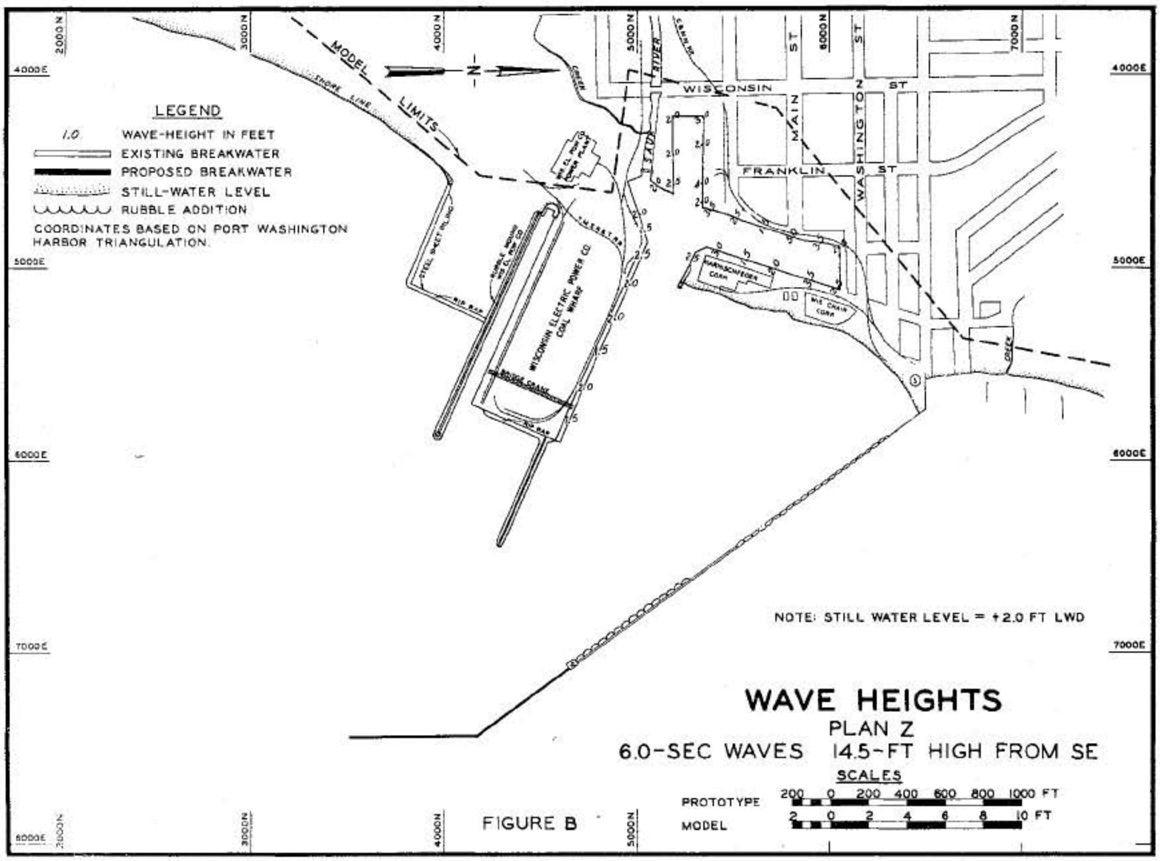

LEGEND
1.0 WAVE-HEIGHT IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL-WATER LEVEL
RUBBLE ADDITION
COORDINATES BASED ON PORT WASHINGTON HARBOR TRIANGULATION.
MODEL LIMITS
SHORE LINE
N
WISCONSIN
FRANKLIN ST
MAIN ST
WASHINGTON ST
SAUK RIVER
WISCONSIN ELECTRIC POWER CO. COAL WHARF
STEEL SHEET PILING
RIP RAP
BRIDGE CRANE
HARNISCHFEGER CORP
WIS CHAIR CORP
NOTE: STILL WATER LEVEL = +2.0 FT LWD
WAVE HEIGHTS
PLAN Z
6.0-SEC WAVES 14.5-FT HIGH FROM SE
SCALES
PROTOTYPE 200 0 200 400 600 800 1000 FT
MODEL 2 0 2 4 6 8 10 FT
FIGURE B

PLATE 47